[redacted] UNCLASSIFIED
EXTRACT

WT-1320 EXTRACT

This document consists of 56 pages

No. 101 of 165 copies, Series A

Operation REDWING

PACIFIC PROVING GROUNDS

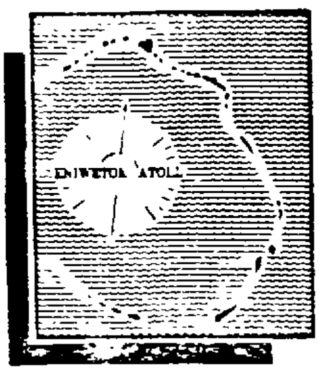
May - July 1956

Project 2.66a

EARLY CLOUD PENETRATIONS(U)

TECHNICAL LIBRARY
MAR 14 1960
of the
a129422

Issuance Date: February 24, 1960



(EXTRACT ONLY) Paul Bons for Clayson/DNA 4/14/85

[redacted]

T[redacted] data as
[redacted]
Its [redacted]
co[redacted] to an unauthorized
[redacted]

THIS IS A SANITIZED VERSION OF WT-1320. THE ORIGINAL DOCUMENT REMAINS CLASSIFIED SECRET RESTRICTED DATA

Paul Bons DNA

HEADQUARTERS FIELD COMMAND, DEFENSE ATOMIC SUPPORT AGENCY
SANDIA BASE, ALBUQUERQUE, NEW MEXICO

DTL019,63C
DNA1.940930.018
HRE-0717

[redacted]

WT—1320 EXTRACT

OPERATION REDWING—PROJECT 2.66a

EARLY CLOUD PENETRATIONS(U)

UNCLASSIFIED

EXTRACT

Ernest A. Pinson, Col, USAF
Kermit C. Kaericher, Capt, USAF
James E. Banks, 1st Lt, USAF
John d'H. Hord, Maj, USAF

Air Force Special Weapons Center
Kirtland Air Force Base, New Mexico

NOTE:
THIS IS A SANITIZED
REPORT OF WT-1320.
THE ORIGINAL DOCUMENT
REMAINS CLASSIFIED
SECRET - RESTRICTED DATA

[redacted] Paul Boren
DNA 11/17/80

[redacted]

[redacted]

DEDICATION

This report is dedicated to Paul Marcus Crumley, Captain, United States Air Force, who gave his life on the 18th day of May, 1956 in the prosecution of this work. He did much of the work of assembling the material and planning all the details necessary to the proper conduct of the project.. May this report and the value of this work stand as a small evidence that he did not die in vain.

ABSTRACT

Twenty-seven penetrations of six radiation clouds from multimegaton-range detonations were made at times ranging from 20 to 78 minutes after detonation and at altitudes ranging from 20,000 to 50,000 feet. Sixteen of these penetrations were earlier than 45 minutes and seven were earlier than 30 minutes.

Maximum radiation dose rates as high as 800 r/hr were encountered, and several flights yielded total radiation doses to the crew of 15 r.

It was found that the average radiation dose rate in the mushroom of the cloud from a 100-percent-fission-yield detonation would be:

$$\bar{D} = 1.0 \times 10^{5} t^{-1.7}$$

Where: $\bar{D}$ = average dose rate, r/hr

t = time after detonation, minutes

This relationship holds for times from 3 to 80 minutes after detonation.

The average dose rate in the stem of the cloud from water-surface bursts was found to be less than the dose rate in the mushroom by a factor of from five to ten. The radiation dose rate in the cloud is independent of yield, but is proportional to the ratio of fission yield to total yield.

In a high tropopause area, a flight through a cloud from a 100-percent-fission-yield multimegaton-range weapon in a high-performance aircraft may be made at 45,000 feet at a time of 20 minutes after detonation. The average mission dose of this flight would be 25 r. At 30,000 feet, a penetration of the stem of the cloud may be made as early as 10 minutes after detonation with a radiation dose of the same magnitude.

The dosage received on the return to base flight because of contamination on the aircraft (B-57B) was found to be about 15 percent of the total mission dose for flights lasting about 50 minutes after the cloud penetration.

An investigation of the internal radiation hazard encountered by the flight crews was conducted. The results are given in Appendix C. The internal hazard was found to be insignificant compared to the external hazard.

FOREWORD

This report presents the final results of one of the projects participating in the military-effect programs of Operation Redwing. Overall information about this and the other military-effect projects can be obtained from WT-1344, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussion of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

PREFACE

The authors wish to acknowledge the assistance of a large number of persons who contributed to the success of Project 2.66.

Doctors W. H. Langham, E. C. Anderson, P. S. Harris, and others in the Health Division of the Los Alamos Scientific Laboratory rendered an invaluable contribution to the project in their assessment of the negligible significance of the internal radiation hazard. This was done by means of measurements in the human counter and urinalyses as reported in Appendix C.

The following members of the Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico, contributed materially to the execution of general or specific parts of the project: Major J. L. Dick and MSgt J. M. Pulliam who assisted in the film measurements of total dose and of contamination on the aircraft, and Capt R. F. Merian, 1st Lt M. V. Harlow, Jr., 1st Lt D. L. Endsley, 2d Lt R. L. Capener, and MSgt W. P. Schaus, Sr., who contributed to the development, maintenance, and repeated calibration of the electronic instruments. The same individuals installed these instruments in the aircraft prior to each shot and read out the data after each shot. Lt Col L. A. Kiley and 1st Lt W. C. Jones rendered excellent rear-echelon logistic support to the project.

G. E. Koch aided the project materially by providing technical advice on the electronic instrumentation at the test site.

The project is indebted to the Tactical Air Command for the assignment of the aircraft and the selection of exceptionally fine officers and maintenance personnel to support the flight requirements of the project. The officers and men of the flight element under command of Lt Col W. B. Furman, performed an outstanding job of maintaining and flying these aircraft. The project officers are grateful to these officers and men for their contributions to the success of the flights and, hence, the success attained by the project.

CONTENTS

[redacted]

TABLES

FIGURES

[redacted]

Chapter 1
INTRODUCTION

1.1 OBJECTIVE

The objective of this project was to measure the radiation dose and dose rate one would experience in flying through the cloud resulting from a megaton-range weapon and some factors affecting personnel safety in the event of an operational situation requiring flights through such clouds.

Specific information was sought on the radiation dose rates inside the cloud, the total dose received in flying through such a cloud, the total dose received on the return flight after flying through the cloud, the internal radiation dose due to inhalation of fission products during such flights, and the conditions of flight inside the cloud.

This information was needed by the operational commands of the Air Force in their planning to insure the most-effective utilization, consistent with crew safety, of aircraft in cloud areas.

1.2 BACKGROUND AND THEORY

During Operation Greenhouse the first significant data on gamma dose rates within atomic clouds were collected. These are reported in Reference 1. The data were collected by drone aircraft flown through the clouds from devices ranging in yield [redacted] at times of from 3 to 25 minutes after detonation. Reference 1 shows average gamma dose rates within the cloud to be of the orders of 10^4 r/hr from 3 to 5 minutes after detonation and 350 r/hr at 20 minutes after detonation.

Further measurements of gamma dose rates within atomic clouds were made during Operation Upshot-Knothole and reported in Reference 2. Dose-rate-measuring instruments were mounted in parachute-borne canisters, and the dose-rate instruments previously used by the Naval Radiological Defense Laboratory (NRDL) during Operation Greenhouse (Reference 1) were mounted in QF-80 drone aircraft. Both the canisters and the QF-80's passed through only the head, or mushroom, of the clouds resulting from devices ranging in size from 11 to 26 kt. Dose rates of the order of 10^4 r/hr were measured from 2 to 6 minutes after detonation.

A compilation of the Greenhouse and Upshot-Knothole average dose rates as a function of time after detonation is presented graphically in Reference 2. These points are also included in Figure 3.2 of this report. The time after detonation for each point is the approximate time after detonation at which the airplane or canister entered the cloud. A least-squares analysis of the data showed that the best-fit line had the equation:

$$\bar{D} = 1.31 \times 10^5 t^{-2.06} \qquad (1.1)$$

Where: $\bar{D}$ = average dose rate, r/hr

[redacted]DATA

t = time after detonation, minutes

Consideration of Reference 2 led to the following generalizations which were used as guides in the initial planning of this project: (1) The dose rate in the cloud is relatively independent of yield. (2) Within a factor of two, the average dose rate in a cloud is given by Equation 1.1.

The first manned penetrations at early times after detonation (17 to 41 minutes) were made during Operation Teapot. These penetrations were made through clouds from devices ranging in yield from 8 to 30 kt. The average dose rate in the cloud as measured during these penetrations is shown graphically in Figure 3.2.

The gamma radiation dose rate within the atomic cloud resulting from kiloton-range weapons has received theoretical consideration in References 3, 4, 5, 6, and 7. The outstanding features of many of these calculations were the very-high gamma dose rates predicted for very early times because of small cloud size and high fission-product concentration.

Chapter 2
PROCEDURE

2.1 OPERATION

Five B-57B aircraft which were instrumented to measure gamma radiation dose
8 rate, integrated dose, and conditions of flight were flown through the clouds resulting from the detonation of six devices ranging in yield from about

On the day prior to a shot, all the instrumentation was checked for proper operation, installed in the aircraft, and readied for use. The flight crews were briefed on the desired flight pattern, altitudes and times of penetrations, and forecast development characteristics of the cloud. These characteristics included size, stabilization levels, and drift.

All aircraft took off at predetermined times in order to permit proper positioning at shot time. After the shot was fired, the cloud was surveyed visually by the director in the lead aircraft. Positions and times of penetration were then established. Penetrations were made at intervals of from 4 to 10 minutes and at varying altitudes. This time spacing permitted some of the results of the first penetrations to be used in planning the succeeding penetrations.

Two types of maneuver were utilized in the penetration phase. In both cases the cloud was approached in straight and level flight. After entering the visible cloud, the pilot either executed a standard 180-degree turn and made his exit or continued on a straight course through the cloud. The type of maneuver to be employed was decided prior to the penetration run. However, the aircrews were briefed on emergency procedures which permitted changing from the straight-through to the 180-degree-turn maneuver at their discretion if excessively high dose rates were encountered. A dose rate two times greater than the predicted dose rate was considered excessive. Upon exit from the cloud, the aircraft returned to base and the records were removed immediately for analysis.

2.2 INSTRUMENTATION

The following instruments and devices were used to obtain data for this project: (1) KAEC Model M1432 automatic-recording radiation ratemeter (P meter); (2) Bioscel (1M-111 (XE-1)/UD) radiation ratemeter; (3) Sigmatron radiation-integrating dosimeter; (4) quartz-fiber dosimeters (Bendix Models 619 and 622), radiation-integrating dosimeter; (5) National Bureau of Standards (NBS) film packs, radiation-integrating dosimeter; (6) Rad-Safe personnel film badge, radiation-integrating dosimeter; (7) AN/PDR-39 (T1B) radiation ratemeter; (8) intervalometer, and (9) photopanel.

The last two were not radiac devices, but were included in this section for convenience of presentation. A description of each device is given below. All radiation-measuring devices were calibrated at NBS prior to the operation. They were recalibrated intermittently at the test site using a Co^{60} source.

[redacted]

2.2.1 KAEC Model M1432 Automatic-Recording Radiation Ratemeter (P Meter). The P meter was designed and built by the West Coast Electronics Laboratory of the Kaiser Aircraft and Electronics Corporation at Palo Alto, California, under contract with and according to specifications furnished by Air Force Special Weapons Center (AFSWC). Seven complete assemblies were procured. The equipment consisted of three air-borne components (probe, power supply, and compressor-amplifier-recorder unit) and one nonair-borne component (playback unit). A block diagram showing the relationship of these units constitutes Figure 2.1.

The entire air-borne assembly was mounted in the nose section of a B-57B. The instruments were operated by the 28-volt aircraft power supply. The wire recorder could be started manually at any time during the flight by means of a switch in the pilot's compartment. It could also be started automatically by use of the intervalometer setting. Once turned on, it continued to record until the recording wire was completely used (about $2\frac{1}{2}$ hours) or until the power was turned off.

The probe was the sensing element and consisted of a Scintilon (trade name used by National Radiac Company) sphere, DuMont 6292 photomultiplier tube, and a re[illegible]ted voltage divider with temperature compensation. This was housed in a $2\frac{1}{2}$-inch diameter aluminum tube having a wall thickness of $\frac{1}{16}$ inch with an added 0.01 inch of tin outside

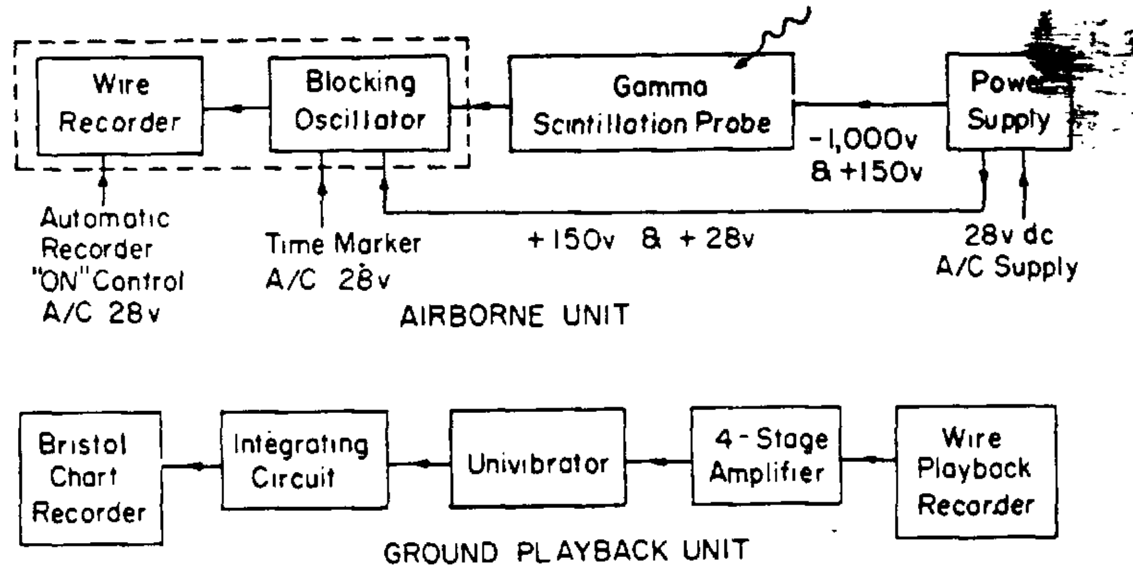


Figure 2.1 Block diagram of automatic recording radiation ratemeter (P meter).

the hemispherical end that covered the Scintilon. The inside of this hemisphere was coated with zinc sulfide in order to enhance low-energy response so that satisfactory performance was obtained from 80 kev up to 1.3 Mev.

The compressor-amplifier-recorder unit received current from (i.e., supplied electrons to) the probe. The intensity of this current varied linearly with the dose rate. This current was supplied by a cathode-biased low-mu triode (CK6152) and resulted in a logarithmic variation of the plate voltage of this tube. This plate voltage was connected to the grid of a blocking oscillator (CK5703WA) through a high resistance. The frequency of the blocking oscillator was thus made to vary as the logarithm of the dose rate, and after amplification through another CK5703WA, the output was impressed on the recording head of the wire recorder.

The power supply consisted of six 26A7-GT tubes connected in parallel so as to

oscillate at about 1,000 cps when fed 28 volts from the aircraft power supply. The output of the tubes was stepped up, rectified, and regulated to result in + 150 volts for B+ voltage in the compressor-amplifier-recorder and − 1,000 volts for the photomultiplier tube in the probe.

The playback unit consisted of a playback recorder of the same type as was used for taking data during penetrations. The frequency-modulated output of the playback unit was amplified, pulse-shaped, and integrated. This integrated, slowly varying direct current was then applied to the input of a standard 12-inch-strip chart recorder (Bristol Model 1892). A logarithmic presentation of dose rates from 1 r/hr to 5,000 r/hr was given on the chart. Calibration tests at NBS using Co^{60} indicated an overall read-out accuracy of ± 20 percent over the range from 1 r/hr to 2,000 r/hr.

2.2.2 Bioscel Radiation Ratemeter. The Bioscel was designed and built by the Evans Signal Laboratory of the U.S. Army Signal Corps in accordance with specifica-

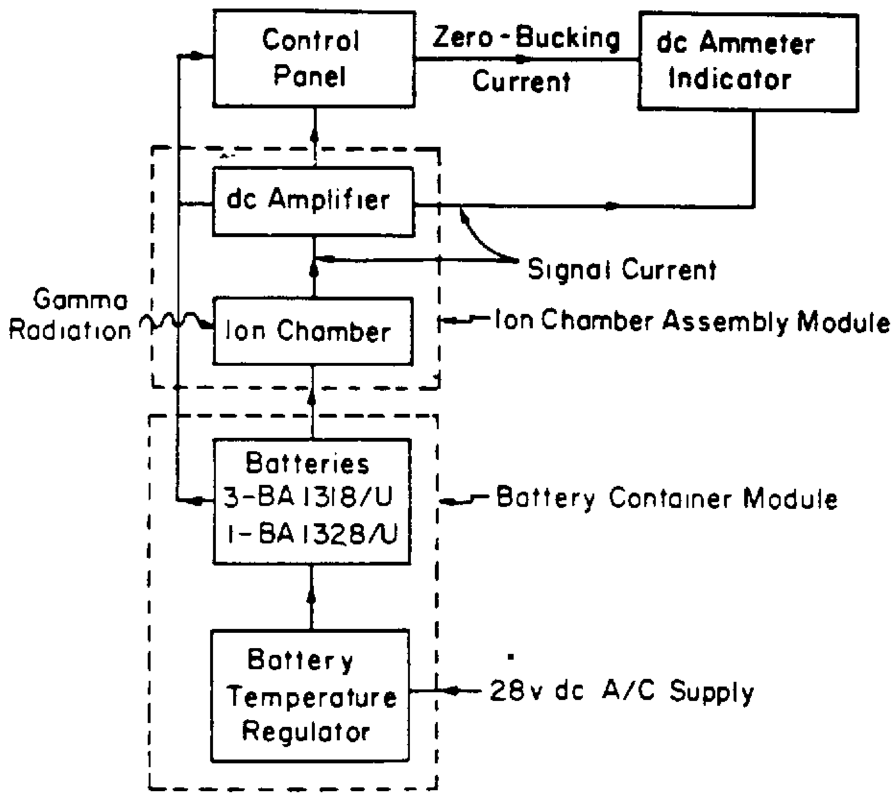


Figure 2.2 Block diagram of Bioscel radiation ratemeter.

tions furnished by AFSWC. Type designation IM-111 (XE-1)/UD was obtained through Army channels. Twenty of these units were procured. Two complete Bioscels were installed in each aircraft with the sensing elements located directly behind the pilot's seat. Data obtained with one instrument were recorded by photographing a remote meter mounted in the photopanel. The remote meter from the second instrument was placed in the pilot's compartment, above and to the right of the instrument panel. As shown in Figure 2.2, the instrument consisted of an ion chamber, an amplifier, a control panel, a battery container, and an indicating meter which presented rates from 1 r/hr to 2,000 r/hr. All these components, except the meter and its cabling, were

contained in a cylindrical aluminum housing 3 inches in diameter and 10 inches in length which had a flange at the control panel for mounting.

The ion chamber and amplifier were potted together in the ion-chamber-assembly module. The potting compound was an epoxy resin, which gave an hermetically sealed unit. The unit passed tests for leakage at −55 degrees Fahrenheit and 0.1 psi. The ion-chamber volume was 85 cm^3. The applied sweep-out voltage was approximately 7 volts. This resulted in nonsaturated operation and produced a roughly logarithmic indication on the meter. Calibration was obtained by varying this voltage between 6.3 and 8.8 volts. Zero adjustment was made before use (or calibration) by adjustment of coarse and fine rheostats in the cathode circuit, through which resistances a voltage drop was obtained to actuate the meter.

The battery box was a separate module from the ion-chamber-assembly module and was located in the end of the tubular aluminum housing farthest from the control panel. It contained three BA-1318/U and one 1328/U batteries. These were sufficient to furnish continuous operation for 200 hours.

2.2.3 Sigmatron Radiation Integrating Dosimeter. The Sigmatron was built by the Research Directorate of AFSWC, Kirtland Air Force Base (KAFB), and was based on a similar design used by Los Alamos Scientific Laboratory (LASL) for a much-lower-range instrument, called the Integron. Eighteen of these units were built. The ion chamber which was used was designed and built by NRDL to meet specifications prepared by AFSWC. The information furnished by the instrument was total gamma dosage, with two ranges (25 r and 100 r full scale) available by changing an internal connection. Two Sigmatrons were used in each airplane, mounted just behind the pilot, with a remote meter for each. One meter was in the photopanel and the other was in the pilot's compartment. The first prototype of this instrument tested at NBS integrated total dosage with an accuracy of ±20 percent at energies higher than about 125 kev. At 80 kev the loss in response was only about 25 percent. Accuracy was independent of rate up to 2,000 r/hr.

A block diagram of the Sigmatron is shown in Figure 2.3. The instrument operated as follows: The ion chamber had a sensitivity of 1.1×10^{-8} amp/(r/hr) and insulation of more than 10^{13} ohms. The integrating capacitors (0.3 and 1.3 μf) had a time constant of more than 3 days. These capacitors were in the electrometer circuit. The ion-chamber current charged whichever capacitor was in use so as to reduce the grid potential of a CK5886 electrometer tube and, hence, increase the positive plate voltage of a CK526AX amplifier tube. This increased plate voltage resulted in an increased cathode current in this tube. This increased cathode current raised the cathode potential and caused a current to flow in the microammeter loop. It also resulted in negative feedback in the input to the CK5886, since it tended to cancel out the voltage produced by charging the integrating capacitors. The negative feedback had the beneficial action of effectively multiplying the capacity of the capacitors without increasing the leakage; hence, the dynamic range of the instrument was extended without exceeding the straight-line portion of the I_p versus I_g characteristic curve of the CK5886.

The three instruments just discussed (P meter, Bioscel, and Sigmatron) all had a response time of less than 1 second for 100 percent response.

2.2.4 Other Dosimeters. The integrated gamma radiation dose during cloud passage and on the return flight was measured by a number of standard integrating dosimeters. Each crew member carried pencil-type dosimeters and a Rad-Safe film badge. Quartz-fiber dosimeters were mounted in the cockpit to record the total dose received on the

mission. The NBS packs were placed in both the pilot's and observer's compartments. The NBS film packs were also mounted in the nose compartment for comparison of the total dose received in the nose with that received in the cockpit. This latter comparison was necessary, because the P meter was mounted in the nose compartment while the sensing elements of all other instruments were in the cockpit.

The AN/PDR-39 (T1B) is a standard Air Force gamma ratemeter and was used to follow the decay rate in the pilot's and observer's positions after completion of the flight. This study was continued for 12 hours. Information concerning this instrument can be obtained through Air Force supply channels.

2.2.5 Intervalometer. The intervalometer, as its name implies, was a device used to actuate the camera in the photopanel at selectable intervals. It was designed and built

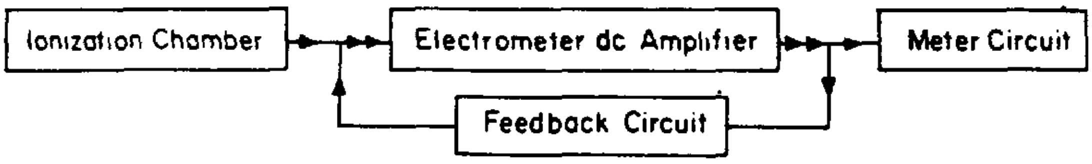


Figure 2.3 Block diagram of Sigmatron radiation-integrating dosimeter.

by the 4925th Test Group (Atomic) at KAFB. One of these instruments, along with the associated photopanel control box was mounted in each airplane. The intervalometer was placed in the nose compartment, and the control box was located to the right of the pilot.

The actuating signals to the camera were fed through microswitches actuated by two separate cams driven by a common motor. This arrangement provided two speeds, "fast" (approximately 3 signals per second) and "slow" (approximately 3 signals per minute). Either could be selected manually by the pilot by means of a switch on the control box. Two camera speeds were required in order to economize on film, yet obtain rapid photographs in the radiation cloud. In addition, there was a third position marked "auto" which automatically changed the speed from "slow" to "fast" when the ambient radiation exceeded a given level, usually set between 1 and 10 r/hr. This part of the circuit is described in the next paragraph.

A dynamotor driven by the airplane's 28-volt power supply provided + 150 volts dc, which was converted to − 700 volts dc by means of a multivibrator, amplifier, and filter. This − 700 volts was connected to ground through an Anton 5980/BS-2 Geiger-Muller tube and a 1.2-megohm resistor. A 0.0001-μf condenser connected the junction of these two elements to the grid of a CK5814 tube and, in conjunction with the resistor, determined the quench of the Geiger-Muller tube. As the radiation field increased, the Geiger-Muller tube broke down more often, sending negative pulses through the condenser to a CK5814 tube. These pulses were amplified and inverted in a subsequent stage and were fed through the coil of a relay. When the repetition rate became sufficiently great (at a rate somewhat lower than the maximum allowed by the quench circuit), the direct-current component of the pulses became sufficient to close the relay, which in turn closed a second relay which switched the interval control from "slow" to "fast." When the radiation rate diminished sufficiently, the interval control reverted to "slow" automatically.

2.2.6 Photopanel. The camera and photopanel located in the nose of the aircraft were used to photograph the meters from the Sigmatron and Bioscel, whose sensing elements were located in the cockpit. Also installed in the photopanel were a clock, altimeter, accelerometer, and airspeed indicator. When correlated with the radiac instrument readings, these gave a record of time in cloud, altitude of penetration, and conditions of flight within the cloud. The photopanel also contained a small marker light. This was controlled by a toggle switch on the photopanel control box. Using this light the pilot could mark the film at specific times, such as cloud entry and exit.

The camera used was a Vought 16-mm recording camera loaded with 100 feet of Eastman Special Emulsion (SO 1112) film. This film is not fogged by gamma doses of

TABLE 2.1 SUMMARY OF SOURCES OF REQUIRED DATA

Data directly available is indicated by x; indirectly available is indicated by 0.

Information Desired on Each Flight	P meter	Bioscel	Sigmatron	Quartz-fiber Dosimeters	NBS Film Packs	Rad-Safe Film Badge	T1B
Total Radiation Dose	x	x	x	x	x	x	—
Time in Cloud	x	x	—	—	—	—	—
Dose in Cloud	x	x	x	—	0	—	—
Dose on Return Flight	x	x	x	—	—	—	0
Maximum Dose Rate in Cloud	x	x	—	—	—	—	—
Average Dose Rate in Cloud	x	x	x	—	0	—	—
Dose Rate at Cloud Exit	x	x	—	—	—	—	0
Decay Rate on Return Flight	x	—	—	—	—	—	0
Contamination Factor	x	—	—	—	0	—	0

less than 500 r. Suitable lighting was included to provide the intense light required for this special film. The lights and the camera utilized the aircraft's 28-volt power supply.

2.3 DESCRIPTION OF REQUIRED DATA

In order to satisfy the purposes of this project, accurate information was required on the following parameters: (1) time of penetration of the radioactive cloud; (2) total radiation dose on the flight; (3) radiation dose accumulated in transit of the radioactive cloud, (4) length of time required to fly through the cloud; (5) radiation dose accumulated on the flight back to base due to contamination on the aircraft; (6) maximum dose rate in the radioactive cloud; (7) dose rate in the crew compartment immediately after exit from the cloud due to contamination on the aircraft; (8) the rate of decay of this contamination, and (9) conditions of flight inside the radioactive cloud, i.e., turbulence and icing.

All of these data, except the last, were recorded automatically with the instrumentation described in Section 2.2. The items of information desired from each flight and the instruments which were used to provide them are summarized in Table 2.1. Most of the information was available directly from the installed instrumentation, while some additional information was obtained by indirect methods as indicated in Sections 2.3.1 through 2.3.9. It should be noted that these indirect methods constituted, in every case, a duplicate method for obtaining a check on the same data obtained by one or more direct measurements.

In addition, the pilot (and observer when present) made observations during the flight on the following parameters: (1) dimensions of the cloud at various altitudes prior to penetration; (2) time and altitude of penetration; (3) type of penetration; (4)

length of time in the radioactive cloud; (5) maximum dose rate in the cloud; (6) dose rate in the cockpit on exit from the cloud due to contamination on the aircraft; (7) accumulated dose in the cockpit at time of exit from the cloud; and (8) degree of turbulence and icing noted during passage through the radioactive cloud.

These observations were reported to the flight director in the air and were transcribed from the pilot's and director's notes during the postflight debriefing. These observations by the pilot duplicated information recorded automatically by the instrumentation in the aircraft in all cases except icing conditions in the cloud.

2.3.1 Total Radiation Dose. The total radiation dose was measured directly by the Sigmatrons, quartz-fiber dosimeters, NBS film packs, and Rad-Safe film badges. It was also obtained by integrating the area under the dose-rate-versus-time curves yielded by the P meter and the Bioscel mounted in the photopanel.

2.3.2 Length of Time in Cloud. The pilot flashed the marker light on the photopanel at the times which he considered to be his entry and exit from the cloud. Time in the visible cloud was then computed by observation of the clock in the photopanel pictures. Time in the radiation cloud was obtained from the P meter and Bioscel data. These two instruments provided curves of dose rate as a function of time. For purposes of this calculation, the entry and exit were considered to be those times at which the dose rate was 5 percent of the maximum rate observed.

2.3.3. Radiation Dose in Cloud. The radiation dose received in the cloud was measured by integration of the area under the P meter and Bioscel curves between cloud entry and cloud exit. The Sigmatron in the photopanel also gave a direct indication of dose in the cloud. It required only that the meter be observed in the film frames where the marker light occurred.

The NBS film packs gave an indirect measure of the dose in the cloud. This was computed by subtracting the return flight dose which was calculated from the T1B decay-rate measurements from the total dose indicated by the film packs.

2.3.4 Dose on Return Flight. The radiation dose on the return flight was measured directly by the P meter, Bioscel, and Sigmatron. In each instance all that was necessary was to subtract the dose in the cloud from the total dose. The difference was the dose received on the return flight.

An indirect method of obtaining that portion of the radiation dose received after exit from the cloud and during the return flight was by extrapolation of the decay-rate curve measured by the T1B after the aircraft was on the ground back to cloud-exit time and integration of the area under the curve from cloud-exit time to time of landing.

2.3.5 Maximum Dose Rate in Cloud. The maximum dose rate in the cloud was taken directly from the P meter and Bioscel curves. The pilot also observed the maximum dose rate indicated by the Bioscel meter in the cockpit.

2.3.6 Average Dose Rate in Cloud. The average dose rate in the cloud was calculated by dividing the dose received in the cloud by the time in the cloud. Both of these were provided directly by the P meter, Bioscel, and Sigmatron. Since the dose in the cloud was obtained indirectly from the NBS film packs, these were also an indirect source for the average dose rate in the cloud.

[redacted]

2.3.7 Dose Rate at Cloud Exit. The dose rate at cloud exit due to contamination on the aircraft was taken directly from the P meter and Bioscel curves. It was also derive by extrapolation of the decay-rate curve from the T1B decay measurements.

2.3.8 Decay Rate on Return Flight. The decay rate of the contamination during the return flight was obtained directly from the P meter curves. It was also obtained by extrapolation of the decay rate curve from the T1B decay measurements made during the first few hours after the aircraft landed.

2.3.9 Contamination Factor. The contamination factor is expressed in percent per minute in the cloud and is defined as:

$$\frac{\text{Dose rate in cockpit at cloud exit}}{\text{(Average dose rate in cloud)(Minutes in cloud)}} \times 100 \qquad (2.1)$$

It is a measure of the degree to which this type of aircraft (B-57B) becomes contaminated by flight through the cloud as reflected by the radiation dose rate in the crew compartment after exit from the cloud. It is significant in predicting that portion of the total dose which is derived from contamination on the aircraft during the flight back to base. It is calculated directly from data recorded by the P meter.

The contamination factor was computed also using the dose rate at cloud exit as derived from T1B measurements and the average dose rate in the cloud indicated by the NBS film packs.

2.4 MASTER DATA SHEET

The large mass of data was summarized on a master data sheet. One of these sheets was filled out for each penetration flight. A typical sheet is shown in Appendix A.

Some additional data on radiation dose rates in the cloud at times later than 1 hour after detonation were obtained through the courtesy of the Test Aircraft Unit. These data were collected during the cloud-sampling operations of this unit.

[redacted]

Chapter 3
RESULTS and DISCUSSION

Twenty-seven penetrations were made through the clouds resulting from the detonation of six devices ranging in total yield from [redacted] These penetrations were made at times of from 20 to 78 minutes after detonation. The indicated altitudes of penetration varied generally from 30,000 feet to 50,000 feet, with one penetration being made at 20,000 feet. Penetrations were made through clouds from land-surface, water-surface, and air detonations.

Maximum dose rates as high as 800 r/hr were encountered in some of the early penetrations, and several flights yielded total radiation doses to the crew of 15 r. On other flights, the whole-body radiation dose as measured by Rad-Safe film badges was as low as 100 mr. The dosage authorized by the Surgeon General of the Air Force and the Commander of Joint Task Force Seven for the aircrews on this project was 50 r, with a limiting planning dosage of 25 r for any single penetration. No penetrations were made in which the maximum dose to be expected, as measured by Rad-Safe film badges, would exceed 25 r.

The experimental plan proved to be satisfactory, and data to satisfy the objectives of this project were obtained. The data are presented in Table 3.1. The sections which follow discuss the results as they appear in the table.

3.1 TIME AND ALTITUDE OF PENETRATION

The times of penetration varied as indicated above. The first penetration on each shot was through the stem of the cloud. Succeeding penetrations were at higher altitudes through the intermediate zone between the stem and mushroom or through the mushroom. All penetrations below 40,000 feet were considered to be penetrations of the stem. Penetrations between 40,000 and 45,000 feet were intermediary between the stem and mushroom. Penetrations above 45,000 feet were in general through the mushroom of the cloud. During Shot Cherokee, a 5,000-foot air detonation, the top of the stem was above 43,000 feet.

3.2 LENGTH OF TIME IN THE RADIOACTIVE CLOUD

The length of time in the cloud recorded in Table 3.1 represents the period of time from the moment the radiation intensity reached a value of 5 percent of the maximum intensity noted in the cloud until the intensity subsequently diminished to this 5 percent value. In penetrations of the stem or mushroom, this time corresponded closely to the time in the visible cloud reported by the pilot. However, in penetrations just below the altitude of the mushroom, the length of time in the radiation field was usually longer than that in the visible cloud by a factor comparable to the time the plane was beneath the overhanging mushroom but was not in the visible cloud. The length of time in the radiation field is used in Table 3.1, since the dimensions of the radiation field are of greater interest in this report than the dimensions of the visible cloud. The time required to pass through the radiation cloud varied from 1 minute for stem penetrations to about 5 minutes for the mushroom penetrations of the clouds from the higher-yield

TABLE 3.1 SUMMARY OF CLOUD PENETRATION DATA

Due to difficulties in instrumentation, the P meter readings are not considered to be as accurate as other monitoring techniques.

SANITIZED

Item	Shot	Time of Penetration Min After Detonation	Indicated Altitude of Penetration	Length of Time in Cloud	Maximum Dose Rate in Cloud r/min		Average Dose Rate in Cloud, r/min			Dose Rate in Cockpit After Cloud Exit mr/min		Contamination Factor of Aircraft, pct/min	
					P Meter	Bioscel	P Meter	Bioscel	NBS Film	P Meter	TIB	From P Meter	From TIB and Film
			ft × 10³	min									
1	Cherokee	75	43	4.2	0.13	0.14	0.04	0.07	0.06	—	0.8	—	0.3
2		68*	40	2.0	—	—	—	—	0.10	—	0.8	—	—
3		59*	39	2.6	0.09	0.12	0.04	0.06	0.06	—	2.0	—	1.2
4	Zuni	78*	46	3.9	1.9	0.33	0.83	0.20	0.25	18	5.0	0.6	0.5
5		68*	44	3.9	1.00	1.03	0.56	0.62	0.37	21	10.0	1.0	0.7
6		52*	41	3.4	0.9	0.92	0.56	0.53	0.44	16	15.0	0.8	1.0
7	Flathead	65	47	2.4	—	—	—	—	0.56	—	10.0	—	0.7
8		78	34										
9		49*	46	2.1	4.4	3.7	2.1	1.9	1.8	32	28.0	0.8	0.7
10		58	44	1.5	—	—	—	—	2.2	—	43.0	—	1.3
11	Dakota	42	48	3.1	3.7	5.0	1.8	2.4	1.9	27	30.0	0.5	0.5
12		38	45	2.8	2.1	3.3	1.0	1.6	0.74	12	15.0	0.4	0.7
13		34	41	3.2	0.16	0.25	0.08	0.13	0.08	—	1.3	—	0.5
14		28	35	1.1	0.33	0.23	0.11	0.05	0.14	—	0.8	—	0.5
15	Apache	44	42	7.0	1.2	1.4	0.83	0.65	0.72	21	29.0	0.4	0.6
16		35	47	5.0	7.7	6.7	3.9	3.3	2.8	77	62.0	0.6	0.5
17		34	45	5.0	7.8	6.7	3.9	2.0	—	94	—	0.5	—
18		45	33	3.1	1.3	0.8	0.61	0.58	—	17	—	0.8	—
19		53	20	0.3	0.22	—	0.22	0.33	—	222	—	300	—
20		28	46	5.2	7.7	—	4.0	—	2.7	65	68.0	0.3	0.5
21		20	41	3.6	3.2	3.3	1.1	1.2	1.5	27	41.0	0.7	0.8
22	Navajo	38	49	4.9	0.67	0.6	0.28	0.25	0.22	—	6.3	—	0.6
23		27	47	4.0	0.67	0.9	0.28	0.42	0.41	—	6.0	—	0.4
24		25	45	4.0	0.94	—	0.39	—	0.32	—	3.2	—	0.3
25		22	40	3.4	0.18	0.25	0.08	0.12	—	—	—	—	—
26		27	37	1.0	0.07	0.08	0.03	0.03	—	—	2.3	—	—
27		33	30	0.7	0.02	0.03	0.01	0.02	—	—	—	—	—

* Indicates 180 degree turn penetration.

TABLE 3.1 CONTINUED

Due to difficulties in instrumentation, the P meter readings are not considered to be as accurate as other monitoring techniques.

Item	Total Integrated Radiation Dose Received on Flight, r						Integrated Radiation Dose Received During Transit of the Cloud, r			Integrated Radiation Dose Received on Flight to Base After Exit from Cloud, r				Total Dose Received After Cloud Exit, pct		Decay Function of Contamination on Aircraft, Negative Exponent of Time	
	P Meter	Bioscel	Sigma-tron	Quartz-Fiber Dosimeter	NBS Film	Rad Safe Film	P Meter	Bioscel	Sigma-tron	P Meter	Bioscel	Sigma-tron	TIB	P Meter	TIB Film	In Flight (P Meter)	On Ground (TIB)
1	0.17	0.3	—	—	0.3	0.3	0.2	0.3	—	—	—	—	0.02	—	—	—	1.34
2	—	—	—	—	0.2	0.2	—	—	—	—	—	—	0.05	—	—	—	1.56
3	0.33	—	—	—	0.2	0.2	0.1	0.1	—	—	—	—	0.06	—	—	—	1.55
4	3.2	0.8	2.0	1.0	1.2	1.2	3.2	0.8	—	—	—	—	0.18	—	15	—	1.54
5	2.7	3.5	2.0	1.8	1.8	2.1	2.1	2.4	1.5	0.6	1.1	0.5	0.34	22	19	1.6	1.64
6	2.4	2.4	2.5	2.1	1.9	1.5	1.9	1.8	1.5	0.4	—	1.0	0.42	19	22	—	1.62
7, 8	—	—	—	—	1.8	1.5	—	—	—	—	—	—	0.46	—	—	—	1.54
9	5.3	5.7	—	5.4	4.8	3.3	4.3	4.2	—	0.8	1.5	—	1.03	16	21	1.7	1.54
10	—	—	6.0	3.4	4.1	3.0	—	—	4.0	—	—	2.0	1.34	—	32	—	1.61
11	6.4	8.8	9.5	8.0	7.2	7.6	5.6	7.5	7.5	0.8	1.3	2.0	0.76	12	11	1.8	1.52
12	3.3	5.2	3.2	2.2	2.6	2.2	2.9	4.6	3.0	0.4	0.6	0.2	0.34	12	13	1.7	1.40
13	0.3	0.4	—	—	0.3	0.3	0.3	0.4	—	—	—	—	0.03	—	—	—	1.70
14	0.1	0.1	—	—	0.2	0.2	0.1	0.1	0.2	—	—	—	0.02	—	—	—	1.21
15	4.8	5.0	7.5	6.0	5.7	5.1	4.4	4.6	6.0	0.3	0.4	1.5	0.70	7	12	1.9	1.37
16	20.5	18.0	—	15.0	15.0	16.0	19.1	16.0	—	1.4	2.0	—	1.20	7	8	1.7	1.45
17	18.6	—	—	—	—	—	17.8	10.0	10.0	0.8	—	—	—	3	—	—	—
18	1.9	12.0	17.0	17.0	17.0	14.0	1.8	1.8	1.2	0.2	—	—	—	9	—	—	1.56
19	7.2	—	—	—	—	—	0.1	0.1	0.2	7.1	—	—	—	99	—	—	—
20	22.2	—	20.0	17.0	15.0	15.0	21.1	—	18.8	1.1	—	1.2	1.10	5	7	1.5	1.39
21	4.4	5.0	7.5	5.1	5.7	4.7	4.1	4.6	7.0	0.3	0.4	0.5	0.44	6	8	1.8	1.44
22	1.4	1.3	—	—	1.3	1.3	1.1	1.1	—	—	—	—	0.20	—	15	—	1.12
23	1.1	1.7	2.5	—	1.8	—	1.1	1.6	2.2	—	—	0.3	0.15	—	8	—	1.13
24	1.3	—	2.3	—	1.4	1.3	1.2	—	2.0	—	—	0.3	0.10	—	7	—	0.95
25	—	—	—	—	—	—	0.3	0.1	0.5	—	—	—	—	—	—	—	—
26	0.4	—	—	—	0.7	0.6	0.06	0.1	0.2	—	—	—	0.06	—	9	—	0.95
27	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

detonations. More-detailed information on cloud size as a function of time after detonation, yield of detonation, and altitude are presented in a later section of this report.

3.3 RADIATION DOSE RATES IN THE CLOUD

The maximum and average radiation dose rates recorded for each penetration by the various instruments previously described are given in Table 3.1. The maximum dose rate recorded on each flight through the cloud was about twice the average dose rate recorded for the total period in the cloud by the same instrument. The average dose rates in the cloud recorded by the P meter and Bioscel were generally 100 percent and 15 percent, respectively, higher than that determined by film dosimetry. Since film dosimetry is more widely accepted as an indicator of whole-body radiation dosage, the film data were used to give dose rates or dosages in all figures and tables presented in this report, unless otherwise specified.

Appendix B shows a typical plot of the dose rates in the cloud recorded by the P meter and Bioscel, together with data which were extracted therefrom for presentation in Table 3.1.

The radiation dose rates observed in the cloud were a function of three primary factors: (1) the nature of the yield of the detonation, i.e., the ratio of the fission yield to the total yield; (2) the altitude at which the penetration was made with respect to the position or height of the mushroom; and (3) the length of time after detonation at which the penetration was made.

DELETED
SECTION
THIS SECTION REMAINS CLASSIFIED

3.3.2 Radiation Dose Rate versus Altitude of Penetration. It was observed in these penetrations that the dose rates at the lower altitudes (30,000 to 40,000 feet) were considerably lower than at higher altitudes in or near the mushroom. Evidently, the radioactive fission-product particles are much more concentrated per unit volume in the mushroom than in the stem. Data on average dose rates versus altitudes from three shots in which penetrations were made at widely differing altitudes between 30,000 and 50,000 feet are shown in Figure 3.1. In this figure all the dose rates are adjusted to 100-percent-fission yield and to a common time of 20 minutes after detonation. It is concluded from these data that the dose rate in the stem of clouds from the water-surface or air detonations of megaton-yield devices at an altitude below 40,000 feet is a factor of one-fifth to one-tenth that in the mushroom. Since the stem is also much smaller in diameter than the mushroom, one can fly through the stem as early as 10 minutes after

[redacted]

detonation without receiving a large radiation dose. The mean free path of gamma radiation is proportional to the density of the atmosphere. Hence, radiation dose rates would be expected to be a factor of two less at 35,000 feet than at 50,000 feet for equal concentrations of fission products per unit volume of cloud. This factor would explain

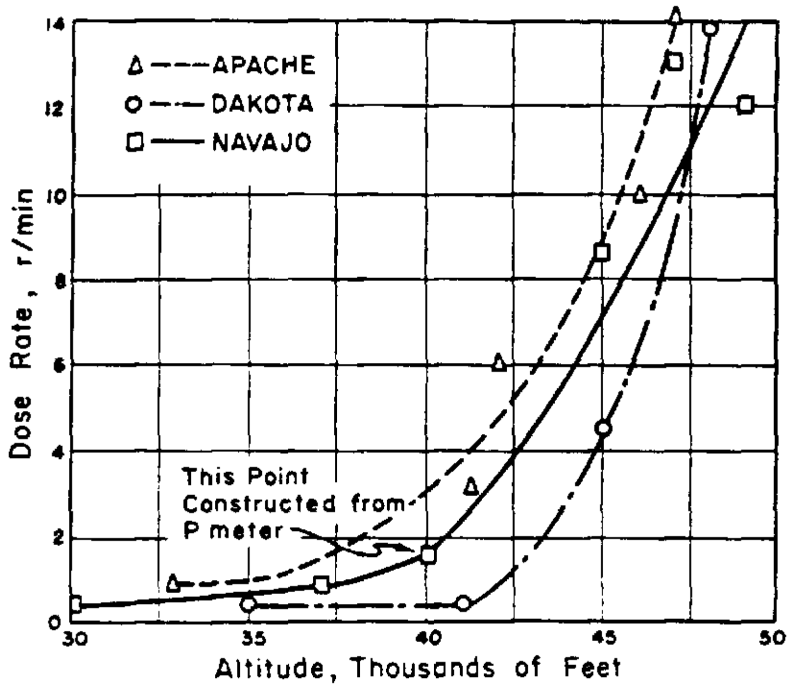


Figure 3.1 Dose rate versus altitude for three shots corrected to 100-percent fission yield and at a time of 20 minutes after detonation.

only a small part of the difference noted between dose rates in the mushroom and in the stem.

The tropopause in the locale where these detonations occurred averaged about 55,000 feet. It is possible that in an area of much lower tropopause the major activity in the mushroom would be constrained to somewhat lower altitudes than suggested by the data presented here. It is the opinion of the authors that the distribution of activity with respect to altitude in clouds from megaton-range detonations would not be greatly altered by a lower tropopause.

As noted from the slope of the curves shown in Figure 3.1, the change in dose rate with altitude would remain essentially constant until the mid-altitude of the mushroom is reached. Above this point the dose rate would tend to decrease.

3.3.3 Radiation Dose Rate versus Time After Detonation. The average radiation dose rate obtained in the various cloud-penetration flights and shown in Table 3.1 were adjusted in accordance with the ratio of fission to total yield for each shot and then plotted against time of penetration. The results are presented in Figure 3.2. Distinctive symbols are used to differentiate the dose rates obtained in various parts of the cloud, e.g., the stem or mushroom. The average dose rates measured in clouds at various times after detonation during Operations Teapot (manned T-33 penetrations), Upshot-Knothole (canisters and drone QF-80 penetrations), and Greenhouse (drone B-17 penetrations) are also plotted in Figure 3.2. A line, determined visually, neglecting

measurements in the stem and giving the most weight to the more recent data, drawn through these data points indicates that the average dose rate in the mushroom of clouds from 100-percent-fission-yield detonations at times from 3 to 80 minutes after detonation is given by the equation:

$$\bar{D} = 1 \times 10^{5} t^{-1.7} \qquad (3.1)$$

Where: $\bar{D}$ = average dose rate, r/hr

t = time after detonation, minutes

This equation does not differ markedly from Equation 1.1 obtained in clouds of kilo-

DELETED SECTION

THIS SECTION REMAINS CLASSIFIED

ton weapons at times from 3 to 20 minutes after detonation.

The average dose rate measured in individual penetrations of such clouds varies by a factor of two above and below the line defined by Equation 3.1. For water-surface or air detonations, data obtained in the stem of the cloud falls below this line by a factor of five to ten, as noted in Section 3.3.2. Since the data presented in Figure 3.2 were collected in clouds from detonations ranging in yield from a

it can be concluded that the average radiation dose rate in these clouds is independent of yield over this range of yields. Data obtained by the Test Aircraft Unit in the cloud-sampling operations of that unit in Operations Castle, Teapot, and Redwing at times from 1 to 5 hours after detonation suggest that, over this interval of time, the slope of the average radiation-dose-rate-decay curve may be as great as −3 to −4. This is probably due to the macrodispersion of the radioactive cloud by the winds during this later time period. At times of less than an hour after detonation, the winds usually have not effected macrodispersion of the cloud. Hence, a slower decay rate function is found at the earlier penetration times at which data for the present project were collected.

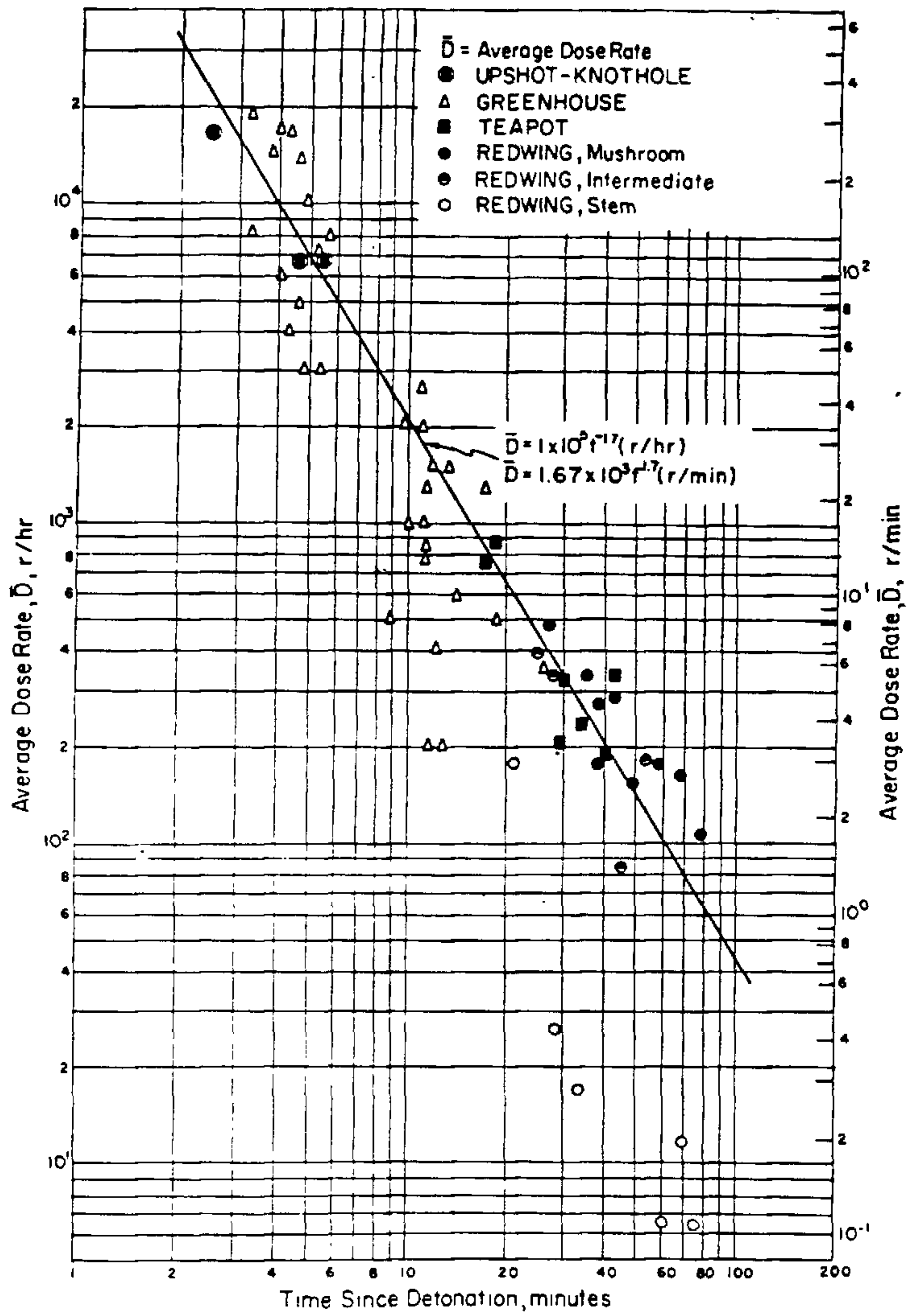


Figure 3.2 Average gamma radiation dose rate in an atomic cloud as a function of time after detonation.

[redacted]

3.4 RADIATION DOSES

The total gamma-radiation dose received on a penetration flight can be broken down into two parts: the dose received in the cloud and the dose received on the return flight. The return flight dose for the B-57B was found to be approximately 15 percent of the total dose when the return flight was of about 50 minutes duration. Section 2.3 of this report explains the various direct and indirect methods used to measure the dosage received by the crew, both in the cloud and on the return flight. Data collected by these various methods is presented in Table 3.1.

The maximum total dose received by any crew member during a penetration flight associated with this project was approximately 16 r, as measured by film dosimetry. It is significant to note that the highest radiation doses received did not correspond to the earliest penetrations. The dose received in the cloud was a function of the average dose rate in the cloud and the time spent in the cloud. For each shot the first penetration usually was made at the lowest altitude, and succeeding penetrations were made at higher altitudes.

This plan was followed so that in the event turbulence was encountered, it could be tolerated better at the lower altitude. Thus the earliest penetrations were made through the stem of the cloud. Since the dose rate in the stem was lower than the dose rate in the mushroom at the same time after detonation and since the diameter of the stem was a third to a half of that of the mushroom, lower dosages were received by the crews who made the earlier penetrations of the stem of the cloud than by those crews who made later penetrations of the mushroom. This was true for all shots.

3.5 CLOUD DIMENSIONS AND TRANSIT DOSES AT VARIOUS ALTITUDES

The total dose received in transit of a radioactive cloud is dependent on two factors: the average dose rate and the length of time required to pass through the cloud. The latter is a function of cloud diameter and the speed of the airplane. All penetrations on this project were made with B-57B aircraft having a speed of about 7 mpm.

Table 3.3 shows representative cloud diameters at various altitudes for detonations of multimegaton yields. The values given in this table are not those measured on any particular shot but are average values for the six shots in which this project participated. The average dose rates, shown in r per minute in the table, are likewise based on the results of the twenty-six penetrations made at altitudes of from 30,000 to 50,000 feet on the six shots. These average radiation dose rates have been adjusted to 100-percent-fission yield. The transit dose, expressed in r, is based on the average cloud diameter shown in the table, the average dose rate shown in the table, and an aircraft speed of 7 mpm.

It should be noted that all the shots during this operation were under a high tropopause (about 50,000 to 55,000 feet). No scientific information was available to this project on cloud size and height for multimegaton-yield devices in an area where the tropopause occurs at a lower altitude. It is the feeling of the authors that the clouds resulting from devices of 0.5 Mt or larger yields would spread out little beneath the tropopause and that a large portion of the cloud would push on through the tropopause.

The information shown in Table 3.3 is based on a time of 20 minutes after a water-surface detonation. Assuming a decay rate in the cloud of $t^{-1.7}$, the average dose rate at 10 minutes after detonation would be about three times that shown in this table. At 40 minutes the average dose rate would be about a third of the value shown. Figure 3.3 shows the comparative size, at various altitudes, of the radioactive clouds at 20 minutes

after detonation for _ devices.

Considering Table 3.3 and Figure 3.3, it may be concluded that one may fly through the cloud from any yield 100-percent-fission weapon in a high-performance aircraft at an altitude of 45,000 feet at 20 minutes after detonation for an expected radiation dose of 25 r. Under the same conditions, one may fly through the cloud (stem) at 30,000 to 40,000 feet as early as 10 minutes after detonation for a radiation dose of 15 r or less.

TABLE 3.3 AVERAGE RADIATION DOSE RATE IN DIAMETER OF, AND RADIATION DOSAGE IN TRANSIT OF, RADIOACTIVE CLOUDS FROM MEGATON-YIELD WEAPONS AT VARIOUS ALTITUDES AT 20 MINUTES AFTER DETONATION

Assumptions: (1) 100-percent-fission-yield detonation; (2) aircraft speed of 420 knots; (3) tropopause at 55,000 feet; and (4) water-surface or air burst.

Altitude	Yield			Yield		
	Cloud Diameter	Radiation Dose Rate	Transit Dose	Cloud Diameter	Radiation Dose Rate	Transit Dose
ft x 10^3	miles	r/min	r	miles	r/min	r
30	5	0.5	0.4	7	0.5	0.5
35	7	0.8	0.8	10	0.8	1.2
40	10	2.5	4	15	2.5	5
45	15	12	25	20	8	25
50	20	10	30	35	15	75
55	0	—	—	40	—	—

3.6 CONTAMINATION FACTOR

The contamination factor was defined and discussed in Section 2.3.9. Values given in Table 3.1 are from computations made using each of the methods of calculation which were described. The average contamination factor for B-57B aircraft is 0.6 ± 0.2 percent per minute. Both methods of calculation gave about the same value. With a contamination factor of this magnitude, a return to base flight of several hours duration after an early penetration of a radioactive cloud would result in a radiation dose to the crew, during the return flight, of about 25 percent of the total dose. One extremely high contamination factor computed for a penetration of the Shot Apache cloud at 20,000 feet is discussed in Section 3.8.

The contamination factor for any particular type of aircraft is a function of the distance between the crew compartment and the residual contamination on the aircraft. In general, the engines are the most highly contaminated portion of the aircraft after flight through a radioactive cloud. Project 2.8 of Operation Teapot measured contamination factors on several different types of aircraft and concluded the contamination factor to be higher for those aircraft where the crew compartment was close to the engine or engines (see Reference 8).

3.7 DECAY OF CONTAMINATION ON THE AIRCRAFT

The two methods used to measure the rate of decay of gamma radiation in the cockpit because of contamination on the aircraft gave essentially similar results, as shown in

Table 3.1. The average slope of the line expressing the decay rate of gamma radiation with respect to time after detonation for five of the six shots was -1.6 ± 0.4. This was in close agreement with the gamma-decay rates found on contaminated aircraft in Operation Greenhouse (Reference 1).

3.8 CONDITIONS OF FLIGHT WITHIN THE RADIOACTIVE CLOUD

An observation of importance made on every penetration was the characteristic brick-red color inside the cloud. This indicates that for daylight penetrations there is a visual characteristic which distinguishes the cloud resulting from a nuclear detona-

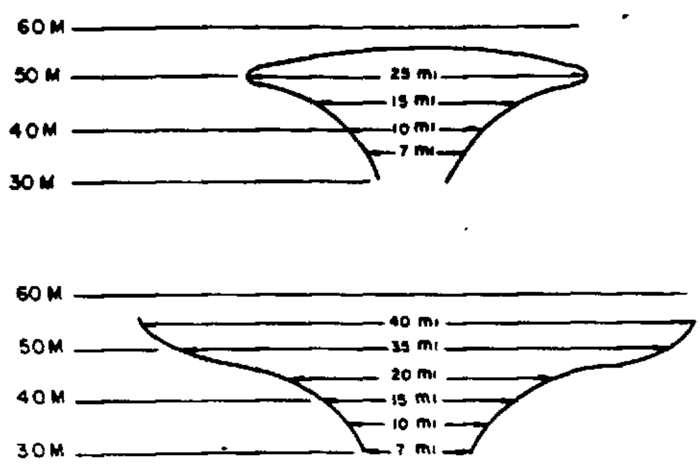


Figure 3.3 Approximate diameters (in miles) of radioactive clouds from and weapons at various altitudes (in thousands of feet) at 20 minutes after detonation.

tion from any other type of cloud formation. This brick-red coloration is due to the formation of oxides of nitrogen in the atmosphere.

Slight to no turbulence was reported by all of the pilots who made a total of twenty-one penetrations on the first five shots. Moderate to severe turbulence was reported by each of five pilots making the six penetrations on Shot Navajo. The time and altitude of penetrations on Shot Navajo were not markedly different from those used on any of the other five shots. No apparent explanation is available for this discrepancy. The turbulence in the Shot Navajo cloud was a short, bumpy type and did not endanger control of the aircraft, according to the pilots. The turbulence was not as great as that encountered in cumulus build-ups in the southwestern United States. It was the unanimous opinion of the pilots making the Shot Navajo penetrations that turbulence would not be a seriously deterrent factor in making a penetration of such a cloud as early as 10 to 15 minutes after detonation.

It is felt that some relationship may possibly exist between the weather conditions existing at the time of the Shot Navajo detonation and the turbulent conditions in the cloud. High cumulus build-ups were prevalent in the area at the time of and subsequent

to the detonation. However, no turbulence was experienced just outside the radioactive cloud during the penetration flights.

Icing was encountered in several of the penetrations of clouds from water-surface detonations. Evidently the radioactive cloud was warmer than the surrounding air and was saturated with moisture carried up from the surface. This was also suggested by the moisture clouds which formed around the radioactive cloud after these detonations. When the relatively cold aircraft flies into the warmer saturated radioactive cloud, moisture condenses and freezes on the aircraft. From 30,000 to 45,000 feet, this icing caused no problem with these aircraft. However, at 50,000 feet, near the maximum altitude capability of these aircraft, this icing was sufficient to result in overheating of the jet engines and made it necessary to reduce power and descend after only a couple of minutes in the cloud. It is not known whether this icing condition would exist in the cloud from a land surface or air detonation.

A penetration of the stem of the cloud from the Shot Apache (water surface) detonation was made at 20,000 feet, 53 minutes after detonation. The maximum dose rate in the cloud, as measured by the P meter, was 0.4 r per minute; the time in the cloud was 20 seconds. There was a large amount of moisture and mud present in the stem of the cloud at this altitude. The leading edges of the aircraft became covered with a visible muddy contamination, which was sufficiently dense on the forward part of the windshield and canopy to obstruct good vision for the pilot. At cloud-exit time the dose rate in the cockpit, because of contamination adhering to the aircraft, was equal to the maximum dose rate experienced inside the cloud. The contamination factor on the aircraft for this penetration was calculated to be 300 percent per minute. This was possible, since so much contamination stuck to the aircraft during the brief time it was in the cloud.

The aircraft was flown through a rain shower about 20 minutes after exit from the radioactive cloud, and the contamination on the aircraft was reduced by a factor of three. Visibility through the windshield returned to normal. The dosage received on the return flight was 99 percent of the total mission dose for this penetration.

The results of this penetration point out the inadvisability of flying through the stem of the cloud from a water-surface detonation. A penetration made at an early time, where the dose rate in the cockpit after exit from the cloud might be quite high, could result in a large mission dose, even though the aircraft was in the cloud for a very short time. It can also be noted that flying through a rain shower as soon as possible after cloud exit is an effective means of reducing the dosage received on the total mission.

3.9 EFFECTIVENESS OF INSTRUMENTATION

Not all of the instrumentation installed in the aircraft operated satisfactorily on every flight. However, in no case did an aircraft penetrate the cloud without sufficient instrumentation functioning properly to provide the necessary data to satisfy the objectives of this project. Film methods were 100 percent successful in measuring the total dose received by the aircrew on the mission. The photopanel functioned on every penetration, with good pictures resulting from each instrument. On one penetration the pilot set the camera speed on the "slow" position, resulting in one picture every 20 seconds while in the cloud, instead of the desired rate of three pictures per second.

The automatic recording instruments were designed to measure radiation rates up to 2,000 r/hr. On penetrations where the dose rates were quite low, continuous data were not obtained on the return flight. In these cases the total mission dose was always less than 2 r. The P meter failed to function on only two of the flights. Thus, satisfactory operation of this instrument was obtained in more than 90 percent of the flights. On

the two occasions where the P meter failed to function, the fault was in the method of installation and not in the instrument itself.

Some trouble was experienced with the Bioscel and Sigmatron. Both these instruments were battery powered. Even with frequent checks of the battery voltages, satisfactory performance was obtained only about 75 percent of the time. Zero drift was especially troublesome in the Bioscel, leading to poor results at low dose rates. The Sigmatron was designed to measure up to 25 r on the low range. Total dosages smaller than 1 r were not reliably indicated by this instrument.

Film measurements were considered to be accurate to ± 20 percent. Measurements made with the T1B were considered accurate to ± 15 percent. The P meter, Bioscel, and Sigmatron were accurate to ± 20 percent when exposed to Co^{60}.

As pointed out in Section 3.3, the P meter gave readings which were about a factor of two higher than film badges. Greater sensitivity and response of this instrument to low energy gamma radiation were thought to be the reasons for this discrepancy. However, a series of tests carried out at the National Bureau of Standards subsequent to the operation have shown that this was not the case.

TABLE 3.4 THE RELATIVE SENSITIVITIES OF RADIATION MEASURING INSTRUMENTS AS A FUNCTION OF X- AND GAMMA RAY ENERGY

Values given are normalized to the response of the P meter at 1,250 kev.

Energy	P meter	Bioscel	Sigmatron	Dupont 502 Film
kev				
38	0.2	0.9	None	< 0.1
69	0.7	1.4	1.0	0.4
118	0.9	1.3	0.9	0.8
169	0.8	1.1	1.2	0.9
215	0.8	1.2	1.3	1.0
660	0.8	1.2	1.0	1.0
1,250	1.0	1.1	1.0	1.0

The P meter and Bioscel were exposed to X- and gamma rays of effective energies from 38 kev to 1,250 kev. Table 3.4 is a compilation of the results of these exposures. The data were normalized to the response of the P meter to gamma rays of 1,250 kev energy (Co^{60}). The values for Dupont 502 photographic film were taken from Reference 9. This emulsion was the component of the NBS film badge which was used in this project. From Table 3.4 it can be seen that the sensitivities of the P meter and the film were nearly the same. Differences in sensitivity, then, could not account for the discrepancy between the measurements taken by the two devices.

A temperature test revealed that the scintillation probe on the P meter was improperly compensated for temperature changes. Decreasing temperature caused an increase in probe current output, i.e., a higher reading. This increase in output varied from probe to probe but was found to amount to a factor of 1.5 to 2.0 at −50C.

An actual flight with the instrument produced a curve which gradually drifted upward. This flight was made at Kirtland Air Force Base. It simulated an actual cloud penetration, insofar as rate of climb and altitude were concerned. At maximum altitude the outside air temperature was between −45 and −50C. A 10 mc Co^{60} radiation source was affixed to the front of the probe and a continuous record was made of the dose rate from engine start to landing. The record showed an increase of 1.8 times the initial reading. This temperature dependence was undoubtedly the cause of the discrepancy between the P meter and NBS film dosimeters.

During the Operation the Bioscei and Sigmatron read 15 percent and 25 percent higher, respectively, than did the film dosimeters. Reference to Table 3.4 indicates that the enhanced response of these two devices to lower energy radiation likely accounted for the differences.

The flight instruments installed in the photopanel functioned properly on each flight. Indicated altitudes were considered to be correct to ± 500 feet. Times of penetration were accurate to the nearest minute.

The accelerometer installed in the photopanel was not considered to be reliable in giving indications of turbulence in flight. The maximum and minimum needles vibrated to the limit of their movement on takeoff. Photographic records were available of the meter fluctuations within the cloud but could not be correlated with the verbal reports of the pilots concerning conditions of flight within the cloud.

[redacted]

Chapter 4
CONCLUSIONS and RECOMMENDATIONS

4.1 CONCLUSIONS

Twenty-seven penetrations of six radioactive clouds from detonations were made at times ranging from 20 to 78 minutes after detonation and at altitudes ranging from 20,000 to 50,000 feet. Sixteen of these penetrations were earlier than 45 minutes after detonation, and seven were earlier than 30 minutes. All penetrations made earlier than 45 minutes were bore-throughs in which the aircraft completely traversed the cloud from one side to the other at the penetrating altitude. Penetrations were made through clouds from air, land-surface, and water-surface detonations. Maximum dose rates as high as 800 r/hr were encountered in some of the early penetrations, and several flights yielded total radiation doses to the crew of approximately 15 r.

Data collected on these flights and in conjunction with past studies of conditions prevailing within clouds from nuclear detonations warrant a number of conclusions regarding the feasibility of flying through such clouds at relatively early times after detonation.

The average and maximum external gamma-radiation dose rates in the mushroom of the cloud from nuclear detonations are dependent on the penetration time and the fission-to-total-yield ratio of the detonation and are independent of the yield of the detonation. The average radiation dose rate in the mushroom of the cloud from a 100-percent-fission-yield detonation as a function of time from 3 to 80 minutes after detonation is given by the equation:

$$\bar{D} = 1.0 \times 10^5 t^{-1.7} \tag{4.1}$$

Where: $\bar{D}$ = average dose rate, r/hr

t = time after detonation, minutes

This average dose rate, $\bar{D}$, may vary by as much as a factor of two for any given penetration.

Beyond 1 hour after detonation, when the mushroom begins to be dispersed by the winds, a more-rapid decay of the radiation dose rate in the cloud is noted in which the slope may be as great as −3 or −4.

The radiation dose rate in the stem beneath the mushroom of clouds from water-surface or air detonations is less by a factor of five to ten than in the mushroom itself.

In clouds from detonations in which the fission yield is less than 100 percent of the total yield, the radiation dose rate is reduced by a factor proportional to the ratio of the fission yield to the total yield.

The accumulated radiation dose that one receives in transit through the cloud is a function of two primary factors: (1) the radiation dose rate in the cloud (related to time after detonation, to the ratio of the fission yield to the total yield, and to the portion of the cloud through which transit is made, i.e., stem or mushroom); and (2) the length of time spent within the cloud as determined by the speed of the aircraft and the horizontal

[redacted]

dimension of the cloud at the altitude of penetration. The diameters of the stem and mushroom increase somewhat with greater yields.

Considering all these factors, two generalizations, substantiated by the penetrations actually flown, may be made: (1) with the tropopause at 55,000 feet, one may fly through the cloud from any yield for a 100-percent-fission weapon in a high-performance aircraft at an altitude of 45,000 feet at 20 minutes after detonation for an expected radiation dose of 25 r; (2) with the same height tropopause, one may fly through the cloud (stem) from any 100-percent-fission weapon at 30,000 feet as early as 10 minutes after detonation for a radiation dose of the same magnitude.

Moderate to severe bumpy turbulence was encountered in one of the clouds penetrated at times of 22 to 40 minutes after detonation. Slight to no turbulence was encountered in the other clouds penetrated during a similar time range. Turbulence was not a problem in any of these penetrations, and it was considered not likely to be a serious problem in a penetration as early as 10 minutes after detonation.

Icing was encountered in some of the penetrations but caused no difficulty, except in the case of two aircraft penetrating a cloud from a water-surface detonation at the maximum altitude of 50,000 feet. This icing forced the pilots of these aircraft to reduce power on the jet engines in order to avoid overheating.

The contamination factor on the B-57B aircraft, as defined herein, averaged 0.6 ± 0.2 percent per minute in penetrations of clouds from air, land-surface, and water-surface detonations. This factor enables one to estimate that portion of the total dose received which is accrued during the flight back to base after exit from the radioactive cloud. In the penetrations made for this project, the return flight took about 50 minutes, and the come-home dose averaged about 15 percent of the total. On return flights of 2 to 3 hours duration in this aircraft the come-home dose would be no more than 25 percent of the total dose for early penetrations of the cloud.

In summary, the radiation hazard in clouds from nuclear weapons denies to aircraft in wartime only a small volume of sky for a short period of time after detonation.

4.2 RECOMMENDATIONS

The information presented above should be used by flying operational commands in planning their defensive and offensive wartime missions.

No consideration should be given to the use of filters in aircraft air intake systems for purposes of restricting entrance of fission-product cloud particles into the crew compartment inasmuch as the hazard to flight personnel from this source has been proved to be insignificant.

Appendix A

TYPICAL MASTER DATA SHEET

Pilot's name, rank, and AFSN:

A/C Number: 527

Home station: Blytheville AFB, Arkansas

Technical observer: None

Shot: Dakota Time and date of shot: 0606, 26 Jun 56

Time of penetration: H + 42 minutes

Type of penetration: Bore-through

Indicated altitude of penetration: 49,500 feet

Pilot's observations:

a. Estimated time in cloud: 180 seconds
b. Highest dose rate in cloud: 350 r/hr
c. Dose rate at cloud exit: 2 r/hr
d. Integrated dose at cloud exit: 11 r
e. Degree of turbulence in cloud: None

Time of exit of crew from aircraft after landing: 0734 (H + 88 minutes)

Instrument data:

1. Dose rate in cockpit at time of crew exit as indicated by:
   a. Bioscel meter in cockpit: 1 r/hr (+ 88 minutes)
   b. T1B in pilot's seat: 400 mr/hr (+ 90 minutes)
   c. T1B in observer's seat: 622 mr/hr (+ 90 minutes)
2. Total integrated radiation dose received on mission as indicated by:
   a. P meter: 11.5 r
   b. Bioscel in photopanel: 6.9 r
   c. Sigmatron in photopanel: 9.5 r
   d. Sigmatron in cockpit: 10 r
   e. Quartz-fiber dosimeters: 8 r
   f. NBS film packs (1) Nose compartment: 8.25 r
      (2) Pilot's compartment: 6.67 r
      (3) Observer's compartment: 7.38 r
   g. Rad-Safe film badge: 7.59 r
3. Time in cloud as indicated by:
   a. P meter: 185 seconds
   b. Bioscel in photopanel: 165 seconds
   c. Marker light in photopanel: 153 seconds
   d. Pilot's estimate: 160 seconds
4. Integrated dose received in cloud as indicated by:
   a. P meter: 10 r
   b. Bioscel in photopanel: 7.5 r
   c. Sigmatron in photopanel: 7.5 r
   d. Sigmatron in cockpit: 8 r
5. Integrated dose on return flight as indicated by:
   a. P meter: 1.4 r
   b. Bioscel in photopanel: 1.3 r
   c. Sigmatron in photopanel: 2.0 r
   d. T1B readings in cockpit extrapolated to cloud-exit time and then integrated: 0.76 r
6. Maximum dose rate in cloud as indicated by:

a. P meter: 400 r/hr
b. Bioscel in photopanel: 300 r/hr
c. Bioscel in cockpit (reported verbally to director): 350 r/hr

7. Average dose rate in cloud as indicated by:
a. P meter: 200 r/hr
b. Bioscel in photopanel: 146 r/hr
c. Sigmatron in photopanel: 146 r/hr
d. Sigmatron in cockpit: 220 r/hr
e. NBS film packs: 114 r/hr

8. Dose rate at cloud exit as indicated by:
a. P meter: 2.9 r/hr
b. Bioscel in photopanel: Too low to indicate accurately
c. Bioscel in cockpit (reported verbally to director): 2 r/hr
d. T1B readings extrapolated to cloud-exit time: 1.8 r/hr

9. Decay rate of contamination on aircraft as indicated by:
a. P meter: −1.8
b. T1B readings: −1.5

10. Contamination factor computed from:
a. P meter data: 0.5 pct per minute
b. NBS film pack data and T1B data: 0.5 pct per minute

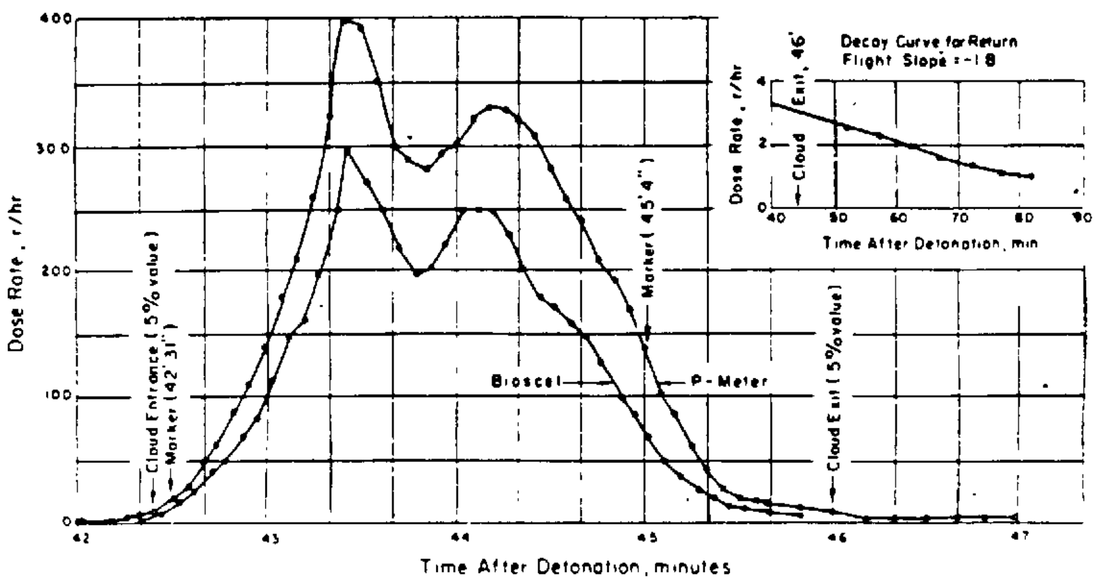
Appendix B

TYPICAL PLOT of P METER and BIOSCEL DATA

Shot: Dakota   Time: 0606, 26 June 1956

A/C Number: 21527

	P meter	Bioscel
Time in radiation cloud	185 seconds	185 seconds
Total dose in cloud	10 r	7.5 r
Maximum dose rate	400 r/hr	300 r/hr
Average dose rate	200 r/hr	146 r/hr
Come-home dose	1.5 r	1.3 r
Total mission dose	11.5 r	8.8 r



Appendix C

EVALUATION of INTERNAL RADIATION HAZARD

This appendix contains the results of an investigation of the internal radiation hazard to which the personnel of Project 2.66 were subjected during the course of Operation Redwing. It is felt that these results are of sufficient importance to be published as a part of the final report for the project. Since this investigation was not a part of Project 2.66 as it was proposed, and since it cannot easily be fitted into the Project 2.66 report, it is reported separately in this appendix.

C.1 OBJECTIVE

Whenever human beings are exposed to fission-product contamination the question arises as to the relative hazards of external radiation exposure and internal radiation exposure from inhaled and ingested material. An evaluation of these two hazards is of great significance and importance to the U.S. Air Force inasmuch as it will affect the design of aircraft pressurization systems and aircrew protective equipment.

Although a considerable amount of experimentation had been done with small animals which were flown through nuclear clouds, the early cloud-penetration project of Operation Redwing was the first instance in which humans were studied in a similar situation.

C.2 BACKGROUND AND THEORY

Several theoretical studies have given some attention to the possible hazard resulting from the inhalation of fission products during flight through nuclear clouds. Two of these (References 5 and 6) have concluded that the hazard is negligible.

The first experimental data on this point were gathered during Operation Greenhouse. These data are reported in Reference 10. In these experiments mice were flown through the stems of atomic clouds in well-ventilated cages on drone aircraft. The mice received external radiation doses ranging from a negligible quantity up to 200 r, as measured by film-pack and thymic-weight-loss methods.

The evaluation of the results was complicated by a large amount of ingested activity as a result of the mice licking their contaminated fur. In spite of the uncertainty in the magnitude of this uptake by ingestion, the total amount of fission products found inside the mice was so small as to indicate that the hazard from internal exposure was negligible with respect to the external gamma radiation dose.

In view of the uncertainties introduced by the indeterminate amount of ingested activity in the above experiment as well as the difficulty in the extrapolation of results from mouse to man, studies were made during Operation Upshot-Knothole using mice and monkeys. The results of these studies are given in Reference 2.

The animals were placed in drone aircraft and flown through the mushroom of the clouds from two detonations. The internal radiation hazard resulting from the inhalation of fission products and unfissioned Pu^{239} and U^{235} during cloud passage appeared to be entirely insignificant compared to the external gamma dose. The ratio of the internal to external radiation hazard was about one to one hundred and was predicted to be independent of weapon yield.

The development of the whole-body radiation counter at Los Alamos Scientific Laboratory (LASL) (Reference 11) provided a powerful new tool for the evaluation of radiation emanating from human beings. It was therefore decided to make extensive investigation of the contamination encountered by the flight crews of the early cloud-penetration project in Operation Redwing. These crews would be the first human beings exposed to the cloud from megaton detonations at early times after detonation. The operational details of these cloud penetrations can be found in Chapter 2 of the main body of this report.

C.3 PROCEDURE

The techniques used for the evaluation of the internal and external contamination of human beings included both counting in the whole-body counter and the analysis of 24-hour urine samples.

Before his departure for the Eniwetok Proving Ground (EPG), each man was sent to Los Alamos for counting in the human counter. These counts established a baseline to which the later post-penetration counts could be compared. A 24-hour urine sample was also collected at this time.

These pilots and observers participated in twenty-seven penetrations of the clouds from five nuclear detonations in the megaton range. These penetrations were made at times from 20 to 79 minutes after detonation and at altitudes of from 20,000 to 49,000 feet. The aircraft were B-57B's. No special filters were installed in the cockpit pressurization system. The pilots and technical observers were given free choice of the setting of their oxygen controls.

A second urine sample was collected from each man during the 24-hour period immediately following his

penetration flight. These samples were flown to Los Alamos for evaluation on the first available sample return flight.

Upon his return to the United States each man again went to Los Alamos for a second counting in the whole-body counter. This second trip to Los Alamos occurred about 5 to 10 days after the penetration flight.

TABLE C.1 RESULTS OF MEASUREMENTS IN HUMAN COUNTER

This table records the data obtained on the high energy (K^{40}) channel.

Column 1	Column 2	Column 3	Column 4
Name	Before	After	Difference
	dis/sec	dis/sec	dis/sec
Shot Cherokee:			
	480	505	25
	465	455	−10
	475	440	−35
Shot Zuni:			
	665	775	110
	545	585	40
	640	590	−50
Shot Flathead:			
	490	600	110
	495	595	100
	480	1,050	570
Shot Apache:			
	490	890	400
	550	3,050	2,500
	490	640	150
	435	830	395
	450	1,450	1,000
	430	2,530	2,100
	510	1,710	1,200
Shot Navajo:			
	470	555	85
	430	590	160
	420	475	55
	375	690	315
Grand Mean Values	490 ± 50	600 ± 100	

C.4 RESULTS AND DISCUSSION

C.4.1 Human Counter. The whole-body counter is a scintillation counter which is capable of detecting the gamma radiation emitted by the human body. These radiations are separated into two energy groups. The lower energy group is nominally attributed to Cs^{137}, while the higher energy group is attributed to K^{40}. The results of these counts are given in Table C.1. Since all the medium-lived fission products which might pose an internal hazard emit a gamma ray of sufficient energy to be recorded on the K^{40} channel, the Cs^{137} channel may be ignored in an assessment of the internal hazard.

The mean value for the K^{40} channel before departure for the EPG was 490 ± 50 dis/sec. The mean value after return from the EPG was 600 ± 100 dis/sec. Thus, it can be seen that the increase in hard gamma emanation from the entire group averaged 110 dis/sec. A value of 220 dis/sec amounts to only 0.006 μc of radioactive material. As will be seen later, this is a wholly insignificant amount.

Of perhaps more interest and significance was the comparison of individual values before and after penetration flights. Reference to Column 4 of Table C.1 shows that the K^{40} excess was near the total group mean for all men except those who penetrated the Shot

Apache cloud. In fact, some showed less activity on their return than before.

Four of the individuals who penetrated the Shot Apache cloud showed hard gamma-excess counts of 1,000 dis/sec or more. These four were A more thorough crystal counter study was performed on ar at Argonne National Laboratories. This study indicated the presence of several intermediate-lived fission products (e.g., Ce^{141}, Te^{132}, I^{131}, La^{140}, etc.) which were on the external surface of the body. The greatest concentration was in the hair of the head. This fact would suggest that the contaminating event was a period of fallout rather than cloud penetration. Both were at the EPG for several weeks after had returned to the United States. Unfortunately, no similar study was made on , but the possibility of external contamination exists and cannot be ruled out.

The correlation of whole-body K^{40} excess count with external gamma exposure is fair, but there is a large variation in count for individuals having nearly the same external exposure. Figure C.1 is a plot of the excess count as a function of external exposure. It can be seen that five individuals having external exposure from 13 r to 16 r had K^{40} excesses of from 400 to 2,500 dis/sec. This is not surprising in view of the fact that at least some of the contamination was known to be external. At least there were no inversions and those having little external gamma exposure showed little or no excess K^{40} count.

The preceding paragraphs imply that the human counter measures total external and internal contamination from gamma emitters. This is, in fact, the case. The builders of the counter consider it accurate to ± 50 percent for this application. The conclusion that can be drawn from the data presented in Table C.1 is that even if all the activity were internal, the body burden of those gamma emitters is negligible. The

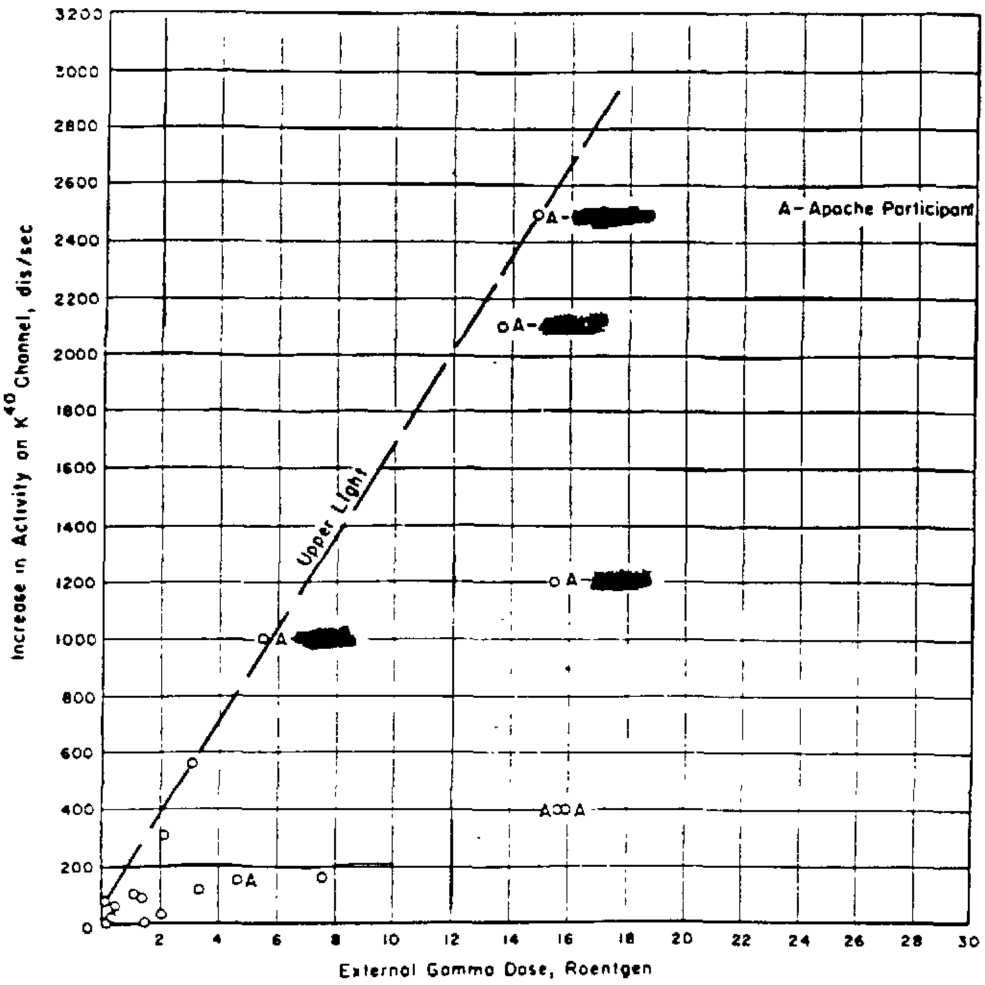


Figure C.1 Increase in whole-body gamma activity as a function of external gamma dose.

[redacted]

NAMES DELETED DUE TO THE PRIVACY ACT

maximum amount observed was less than 0.07 μc. None of the gamma-emitting fission products except I^{131} have maximum permissible body burdens of less than 5 μc, while most are 100 μc or more. The maximum permissible body burden for I^{131} is 0.3 μc. The greatest observed activity was less than one fourth of this. All the counts were made within the period of one half life for I^{131}. Thus, if all the activity were due to I^{131}, the body burden could not possibly be more than one half the maximum permissible amount. The possibility of internal hazard from gamma emitting fission products is therefore conclusively eliminated in the case of flights through clouds from nuclear detonation.

C 4.2 Activity in Urine. Gamma Activity. The 24-hour urine samples which were collected at the time of the visit to the human counter and after cloud penetration were also counted in the human counter. The results of these are shown in Table C.2. In no case was there any significant amount of activity. Therefore, the degree of internal contamination will be judged from the beta activity.

Beta Activity. The 24-hour urine samples which were collected immediately after the penetration flights were measured for gross beta activity. In order to establish some sort of a baseline for normal individuals not exposed to radiation and for individuals at the EPG who did not participate in cloud penetration flights, samples were also collected from persons in these categories. Aliquots of these urine samples were subjected to gross beta analysis. The data collected are given in Table C.3.

TABLE C.2 GAMMA ACTIVITY IN URINE AS MEASURED IN HUMAN COUNTER (K^{40} CHANNEL)

Column 1	Column 2	Column 3	Column 4
Name	Before	After	Difference
	(dis/sec)/sample*	(dis/sec)/sample*	(dis/sec)/sample*
Shot Cherokee:			
[redacted]	8	4	−4
[redacted]	0	0	0
[redacted]	3	4	1
Shot Zuni:			
[redacted]	0	12	12
[redacted]	0	3	3
[redacted]	0	3	3
Shot Flathead:			
[redacted]	0	0	0
[redacted]	0	0	0
[redacted]	7	3	−4
Shot Apache:			
[redacted]	2	6	4
[redacted]	5	25	20
[redacted]	7	0	−7
[redacted]	0	12	12
[redacted]	0	4	4
[redacted]	—	33	—
[redacted]	—	0	—
Shot Navajo:			
[redacted]	3	0	−3
[redacted]	0	0	0
[redacted]	—	0	—
[redacted]	0	3	3

* Samples collected for 24-hour period.

[redacted]

NAMES DELETED DUE TO
THE PRIVACY ACT

TABLE C.3 BETA ACTIVITY IN URINE SAMPLES

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Group, Name, External γ Dose	Volume 24 hours	Ash Wt/ 100 ml	Total β Activity	Counter Efficiency	Total β Activity	Specific β Activity
r	ml	gram	counts/min	pct	dis/min	(dis/min)/ml
Los Alamos Employees:						
[redacted] 0	820	1.23	1,591	35.5	4,490	5.47
[redacted] 0	1,175	1.45	2,162	34.0	6,370	5.42
[redacted] 0	2,300	1.05	3,036	37.0	8,200	3.56
[redacted] 0	760	0.92	1,854	37.5	4,950	6.52
				Group Mean	6,000 ± 1,300	5.24 ± 0.84
Cherokee:						
[redacted] 0.3	600	1.28	840	35.5	2,370	3.95
[redacted] 0.2	1,050	0.58	724	38.5	1,880	1.79
[redacted] 0.2	670	1.50	884	33.5	2,640	3.94
				Group Mean	2,300 ± 280	3.23 ± 0.96
Zuni:						
[redacted] 1.2	380	2.81	752	29.5	2,540	6.68
[redacted] 2.1	810	2.21	1,247	30.0	4,160	5.14
[redacted] 1.5	950	2.21	893	30.0	2,980	3.14
				Group Mean	3,230 ± 620	4.99 ± 1.23
Apache:						
[redacted] 16.0	1,570	1.11	4,255	37.0	11,500	7.33
[redacted] 14.8	670	1.19	5,990	36.5	16,400	24.5
[redacted] 4.7	780	2.24	1,100	30.0	3,670	4.70
[redacted] [illegible]	970	1.20	5,461	36.5	14,950	15.4
[redacted] [illegible]	1,360	2.48	2,774	30.0	9,240	6.8
[redacted] 13.6	800	1.82	8,858	30.5	29,100	36.4
[redacted] 15.5	2,100	0.92	3,318	37.5	8,850	4.21
				Group Mean	13,390 ± 5,800	14.2 ± 9.6
Maintenance Crews:						
[redacted] 0.3	1,650	1.43	1,502	34.0	4,420	2.68
[redacted] 0.2	670	2.66	978	30.0	3,260	4.87
[redacted] 0.5	1,770	0.99	2,496	37.5	6,650	3.76
[redacted] [illegible]	520	2.87	853	30.0	2,840	5.46
[redacted] [illegible]	400	3.26	412	29.5	1,400	3.50
[redacted] [illegible]	940	2.55	1,241	30.0	4,140	4.40
				Group Mean	3,785 ± 1,265	4.11 ± 0.80
Non-Flying Project Personnel:						
[redacted] 1.2	[illegible]	2.19	846	30.0	2,820	3.13
[redacted] 1.5	710	1.98	873	30.0	2,910	4.12
[redacted] 3.5	1,410	[illegible]	2,143	31.5	6,810	4.83
[redacted] 1.2	1,460	0.72	1,825	38.0	4,800	3.29
[redacted] 2.5	2,630	1.61	3,551	32.5	10,900	4.14
				Group Mean	5,650 ± 2,550	3.90 ± 0.55

[redacted]

NAMES DELETED
DUE TO THE PRIVACY ACT

Column 1 of Table C.3 gives the name of each individual, his participation, and accumulated external gamma dose. Columns 2, 3, 4, and 5 are self-explanatory and give the data associated with the counting procedure.

Almost all beta activity in normal urine is from the excretion of K^{40}. The authors of Reference 12 have determined the daily urine excretion of potassium to be about 3 grams. This is equivalent to 5,400 beta dis/min. This compares favorably with the experimental values for the Los Alamos employees who were not exposed to radiation (6,000 ± 1,300). Column 6 of Table C.3 shows the total number of dis/min observed for all urine samples. It will be noted that of the eight points which lie above the normal range, six were from Shot Apache, one was a non-penetrating EPG control, and one was an unexposed Los Alamos employee. The seventh Shot Apache participant was well below the normal range. Nearly all of the other individuals were also well below this normal range.

Since so many of the values for total beta activity lie below the normal range, it was thought that perhaps loss of potassium through perspiration might account for these low values. Reference 13 gives the chemical composition of sweat to be 21 to 126 mg of potassium per 100 ml of sweat (cf. 29 to 294 mg of sodium per 100 ml). The maximum rate of sweat production is given as 17.7 to 38.2 ml/min. Assuming a potassium concentration of 50 mg/100 ml and a sweat production of 10 ml/min (not unreasonable at the EPG), a man could excrete as much as 1 gram of potassium in about $3\frac{1}{2}$ hours.

No data are available on the actual amount of perspiration produced by the individuals under consideration. However, it seems reasonable to expect an inverse relationship to exist between urine volume and sweat production. Therefore, the total beta activity of the urine (Column 6) was divided by the total urine volume (Column 2). This quotient is shown in Column 7.

The mean value for the unexposed Los Alamos employees was 5.2 ± 0.8 (dis/min)/ml. Examination of the data revealed that five of the seven individuals who were above this normal range were Shot Apache participants, one was a Shot Zuni participant, and one was an unexposed Los Alamos control. All others, including two Shot Apache participants, were within or below the normal range.

There is no correlation between urine activity and external gamma dose when either method of expressing urine activity is used. The two plots of urine activity as a function of external gamma dose are given in Figures C.2 and C.3.

Total urine beta activity is expressed as a function of hard gamma excess counts from the human counter in Figure C.4. There is a suggestion of a correlation between the two, but it certainly is not a good one.

The radioactive decay of several of the urine samples was followed. The apparent radiological half times of the activity in these urine samples were about 4.5 days and 60 days. Fission products having half lives near 4.5 days are Sr^{89}, Zr^{95}, and Y^{91}. Two having half lives of about 60 days are Te^{132} and Mo^{99}. It is emphasized that these isotopes were not specifically identified.

All the urine residues were sent to the Lamont Geophysical Laboratory of Columbia University to be analyzed for Sr^{90}. In no case was any significant amount found.

The samples were analyzed for plutonium at LASL. The results are shown in Table C.4. According to Reference 14 the maximum permissible concentration of plutonium in urine is 3×10^{-9} µc/ml or 7 (dis/min)/liter. The highest value observed here was 0.67 (dis/min)/liter, while most were much lower. In fact, these levels are such as are frequently characteristic of people who have had no exposure to plutonium.

The significance of beta activity in urine can be summarized as follows: Beta activity in urine indicates activity within the body and is probably a true measure of the amount of internal fission-product contamination provided that the sample is not contaminated from an outside source during its collection. This contamination is a real possibility when the individual or his environment has been subject to fallout.

Except for those individuals who participated in Shot Apache, all the beta activity was attributable to the excretion of natural K^{40}. All others showed no internal contamination down to the limit of detection. This limit was about 1×10^{-3} µc or 2,250 dis/min. The normal daily K^{40} excretion was about 2×10^{-3} µc or 4,450 dis/min.

It is possible that the urine samples from the Shot Apache participants owed their activity to external contamination, inasmuch as two of the men [redacted] and [redacted] were known to have had considerable surface contamination on their bodies. In any event, the levels observed were too low to constitute an internal radiation hazard.

C.5 CONCLUSIONS

A number of conclusions can be drawn from the data which are presented here.

1. No internal radiation hazard arises from flights through thermonuclear clouds, regardless of the oxygen control setting. Urine samples showed no significant amounts of gamma-emitting fission products, beta-emitting fission products, or unfissioned plutonium.

2. Flight through thermonuclear clouds may lead to some external fission-product contamination, but the amount is not significant from the standpoint of radiation hazard.

3. Individuals who participate in nuclear test operations, but who do not fly through thermonuclear clouds,

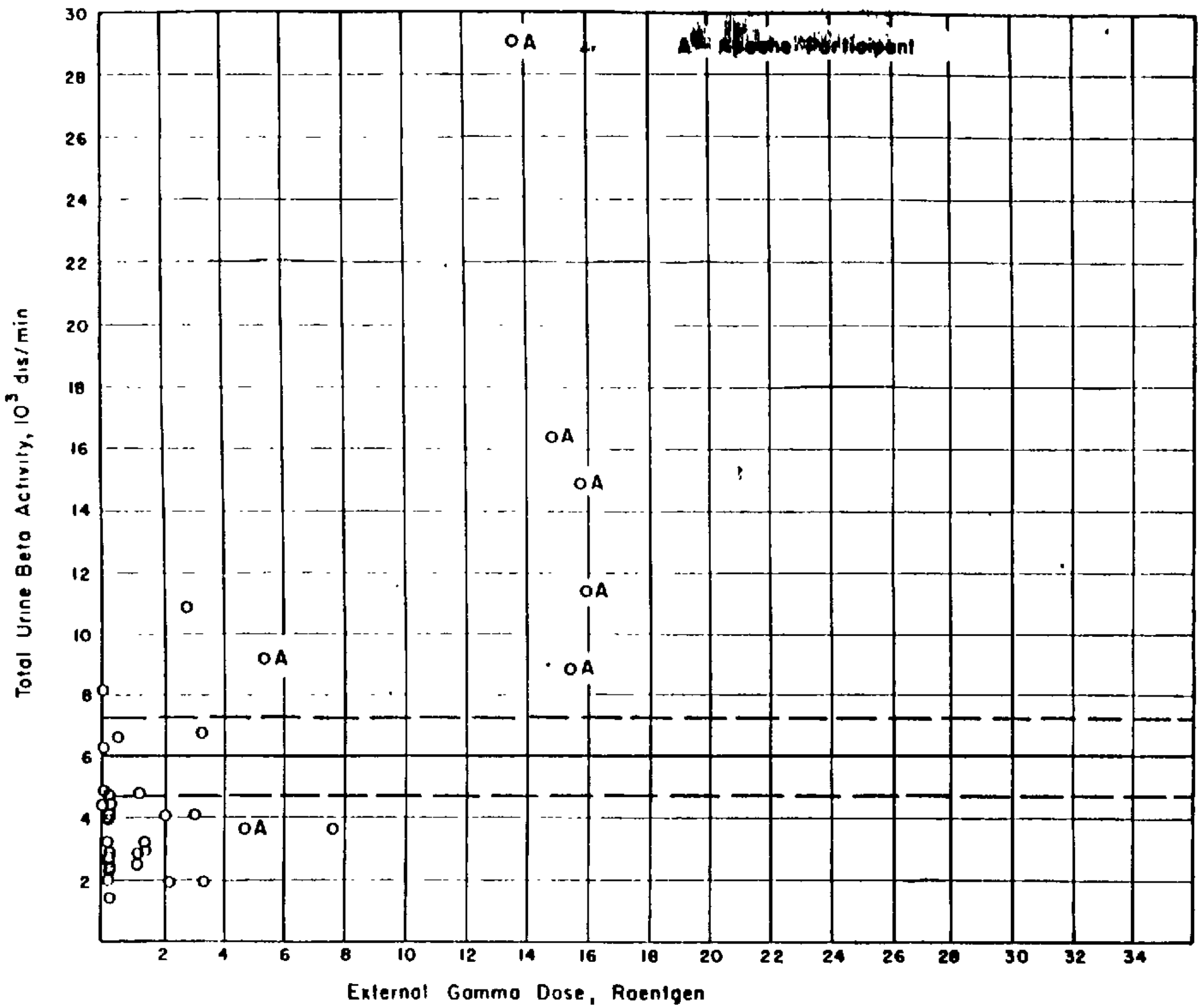


Figure C.2 Total beta activity in urine as a function of external gamma dose.

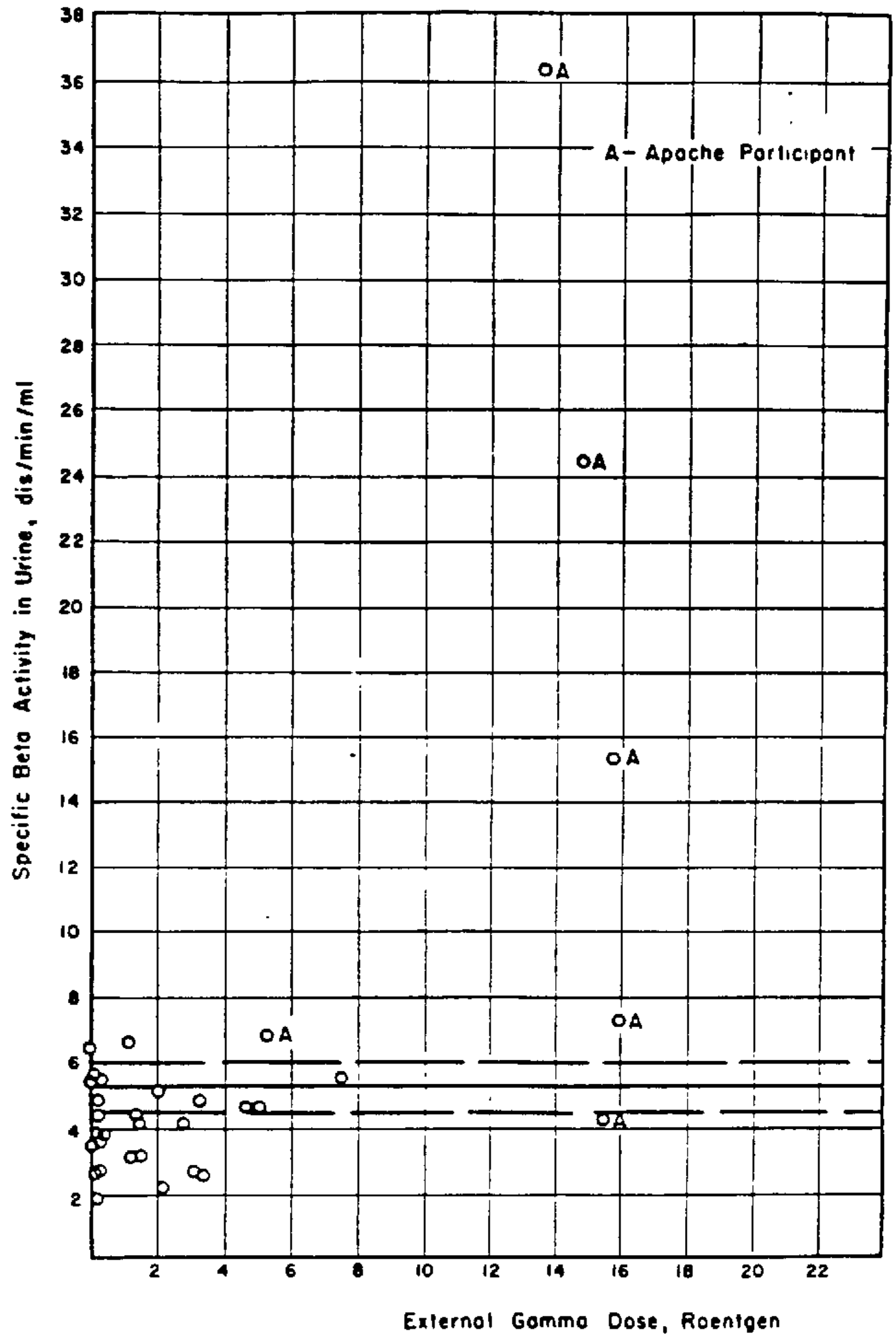


Figure C.3 Specific beta activity in urine as a function of external gamma dose.

[redacted]

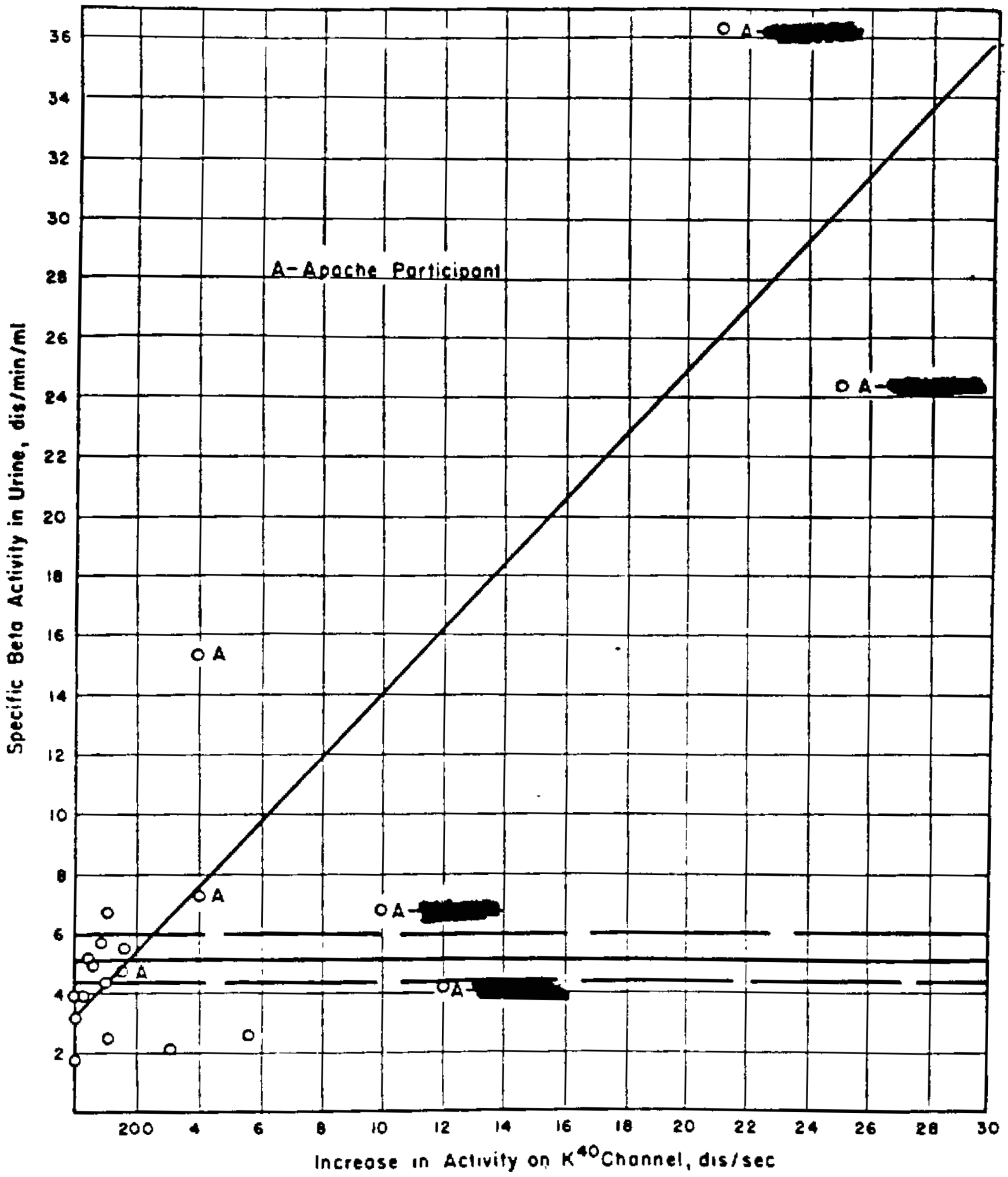


Figure C.4 Specific beta activity in urine as a function of increased gamma activity as measured in human counter.

[redacted]

DELETED PAGE

PAGE 50 REMAINS CLASSIFIED

do not exhibit internal activity which is significantly different from the ordinary population.

C.6 RECOMMENDATIONS

It is recommended that no action be taken to develop filters for aircraft pressurization systems nor to develop devices to protect flight crews from the inhalation of fission products.

[redacted]

REFERENCES

1. G.E. Koch; "Cloud Radiation Field"; Annex 6.8, Operation Greenhouse, WT–11, August 1951; U.S. Naval Radiological Defense Laboratory, San Francisco, California; Secret Restricted Data.

2. W.H. Langham and others; "The Radiation Hazards to Personnel Within an Atomic Cloud"; Project 4.1, Operation Upshot-Knothole, WT–743, December 1953; Air Force Cambridge Research Center, Cambridge, Massachusetts; Secret Restricted Data.

3. P. Callentine; "The Radiation Dose to be Expected from Aerial Penetration of an Atomic Cloud"; LA–1308, November 1951; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; Secret Restricted Data.

4. S.T. Cohen and E.H. Plesset, "The Radiation Hazard from an Atomic Cloud"; Project Rand, R–139, April 1949; Rand Corporation, Santa Monica, California; Secret Restricted Data.

5. J.D. Teresi; "Radiation Hazards to Aircrews Exposed to the Atomic Cloud of an Atomic Detonation"; USNRDL–379, December 1952; U.S. Naval Radiological Defense Laboratory, San Francisco, California; Secret Restricted Data.

6. H.D. Landahl; "Calculations of the Hazard Involved in Passage Through a Radioactive Cloud Resulting from a Nominal Atomic Bomb"; Quarterly Progress Report No. 1, October 1951; USAF Radiation Laboratory, University of Chicago, Illinois; Official Use Only.

7. Annex 2.4, Operation Greenhouse, WT–43, 1951; U.S. Joint Task Force Three; Secret Restricted Data.

8. W.J. Nicholson and others; "Evaluation of Some Factors Influencing Radiation Dosage from Penetration of an Atomic Cloud by Manned Aircraft"; AFSWC–TN–56-30, June 1956, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico; Secret Restricted Data.

9. E. Storm and E. Bemis; "Gamma Radiation as a Function of Distance"; Project 13.3a, Operation Teapot, WT–1208, October 1955; Los Alamos Scientific Laboratory, Los Alamos, New Mexico; Secret Restricted Data.

10. E.C. Anderson and others, "Investigation of the Radiation Hazards Associated with Passage Through an Atomic Bomb Cloud"; Annex 2.4, Operation Greenhouse, Section 3, WT–43, 1951; U.S. Joint Task Force Three; Secret Restricted Data.

[redacted]

11. E.C. Anderson and others; "The Los Alamos Human Counter"; Nucleonics, January 1956, Page 26; McGraw-Hill Publishing Company, Inc., New York, New York; Unclassified.

12. E.C. Anderson and others; unpublished article.

13. "Handbook of Biological Data"; 1956; National Research Council, W.S. Spector, Ed.; W.B. Saunders and Co., Philadelphia, Pennsylvania; Unclassified.

14. "Principles of Radiation and Contamination Control"; 1956; U.S. Naval Radio-

11. E. C. Anderson and others; "The Los Alamos Human Counter"; Nucleonics, January 1956, Page 26; McGraw-Hill Publishing Company, Inc., New York, New York; Unclassified.

12. E. C. Anderson and others; unpublished article.

13. "Handbook of Biological Data"; 1956; National Research Council, W. S. Spector, Ed.; W. B. Saunders and Co., Philaoelphia, Pennsylvania; Unclassified.

14. "Principles of Radiation and Contamination Control"; 1956; U. S. Naval Radiological Defense Laboratory, San Francisco, California; Unclassified.

DELETED PAGES

PAGES 55-56
REMAIN CLASSIFIED